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EVALUATION OF RESIN-IN-PULP TECHNOLOGY FOR CANADIAN GOLD ORES - PHASE II

PROJECT NO. 5251

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Witteck Development also is grateful to Dow Chemical Inc. for producing and supplying sufficient quantities of the Dow experimental resin XU-40114.00 for the duration of this pilot plant campaign.

1.0 SUMMARY

A ten-day pilot plant campaign to demonstrate the resin-in-pulp process has been completed. The objectives of the program were to:

- Confirm that the benchscale flowsheet developed during Phase I is operative on a pilot scale.
- Confirm the adsorption capacity and selectivity of the chosen resin for gold.
- Confirm that acceptable barren levels (0.01 mg/L gold) can be attained.
- Confirm the resin elution characteristics for gold recovery.
- Evaluate long-term resin poisoning, scaling and attrition by recycling the resin through multiple adsorption/elution cycles.
- Monitor resin handling procedures.

Due to a combination of inconsistent resin characteristics (adsorption capacity and elution performance) and process scale-up problems, not all of the program objectives were achieved.

While the gold selectivity of the resin batches did not vary significantly, the gold adsorption capacity of the resin used herein was lower than that tested during the Phase I program. Also, the resin received for the pilot program could not be eluted to the required residual gold level in a reasonable number of eluant bed volumes (e.g. 10 to 15).

Consequently, acceptable barren levels (0.01 mg/L gold) in the treated pulp were not obtained during the pilot operations. However, by utilizing fresh resin rather than eluted resin, and by increasing the resin to pulp flow ratio, a barren level of 0.1 mg/L gold was achieved.

Due to the excessive number of eluant bed volumes required for elution, the resin could not be recycled through multiple adsorption/elution cycles. Thus long-term resin poisoning and scaling information could not be obtained. However, the evaluation of resin attrition was completed in an independent study. Resin attrition was found to be negligible compared to carbon attrition under similar operating conditions.

Resin handling was not a problem. The plus 32 resin was retained efficiently by the 48 mesh interstage screens. All of the resin added to the RIP circuit was recovered within experimental error. In practice, the resin bead and interstage screen sizes would be larger and comparable to those used in CIP operations.

As a result of the resin performance anamolies, a follow-up laboratory test program was designed and completed to support the tentative conclusions drawn from the pilot plant results.

Prior to any future pilot testing, the economic merit of the RIP process should be evaluated using, in part, the information obtained during the Phase I and II programs. An engineering feasibility study is recommended to examine estimated operating and capital costs for the resin-in-pulp process compared to those for the carbon-in-pulp process which is in common commercial use. In the absence of design information confirmed by pilot plant operation, comparative kinetic measurements on resin and carbon can be coupled with available mathematic modelling

techniques. This process simulation can generate the number of stages, resin concentration and loading, and the steady state resin and solution gold levels. The results of the feasibility study will indicate if there is sufficient economic justification for further piloting of the process.

If piloting is warranted, a detailed resin evaluation program is recommended prior to planning of the pilot campaign. This should be done using a large batch of the experimental resin.

1.0 SOMMAIRE

On a exécuté une campagne de dix jours en installation-pilote pour démontrer le fonctionnement du procédé résine/pulpe. Les objectifs du programme étaient les suivants:

- Confirmer que le processus de traitement élaboré par essais en laboratoire au cours de la phase I est opérationnel à l'échelle de l'installation-pilote.

- Confirmer la capacité d'adsorption et la sélectivité de la résine choisie à l'égard de l'or.

- Confirmer qu'il est possible d'atteindre des niveaux d'épuisement acceptables (0,01 mg d'or par litre).

- Confirmer les caractéristiques d'élution de la résine pour le recouvrement de l'or.

- Évaluer les caractéristiques d'empoisonnement à long terme de la résine, et les caractéristiques de formation de dépots et d'attrition en soumettant la résine à de nombreux cycles adsorption/élution.

- Contrôler les méthodes de manipulation de la résine.

Du fait de la combinaison de caractéristiques non reproductibles de la résine (capacité d'adsorption et rendement lors de l'élution) et de problèmes suscités par l'augmentation de l'échelle de traitement, il n'a pas été possible de réaliser tous les objectifs du programme.

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Tandis que la sélectivité des lots de résine à l'égard de l'or n'a pas varié sensiblement, la capacité d'adsorption de la résine utilisée à l'égard de l'or a été inférieure à celle observée au cours de la phase I du programme. De plus, il n'a pas été possible de soumettre la résine reçue pour le programme pilote à l'élution jusqu'au niveau résiduel d'or désiré dans un nombre raisonnable de volumes d'éluant (c.-à-d. 10 à 15).

De ce fait, on n'a pu obtenir des niveaux d'épuisement acceptables (0,01 mg d'or par litre) dans la pulpe traitée au cours des opérations en installation-pilote. Cependant, en employant une résine fraîche plutôt qu'une résine éluée, et en augmentant le rapport résine/débit de pulpe, on a pu obtenir un niveau d'épuisement de 0,1 mg d'or par litre.

Du fait du nombre excessif de volumes d'éluant nécessaires pour l'élution, on n'a pu recycler la résine par une succession de cycles multiples adsorption/élution. On n'a donc pas pu obtenir les renseignements recherchés au sujet de l'empoisonnement à long terme et de la formation de dépôts. Cependant, on a pu effectuer l'évaluation de l'attrition de la résine dans le cadre d'une étude indépendante. On a constaté que l'attrition de la résine était négligeable par comparaison à l'attrition du carbone dans des conditions d'exploitation similaires.

La manipulation de la résine n'a pas constitué un problème. Les particules de résine "plus 32" ont été retenues efficacement par des tamis intermédiaires de 48 mesh. Toute la résine ajoutée dans le circuit RIP a été récupérée, dans les limites des erreurs expérimentales. En pratique, la taille des grains de résine et du tamis intermédiaire serait plus élevée et comparable à celle utilisée dans les opérations CIP.

WD1

Du fait des anomalies de rendement de la résine, on a élaboré et exécuté un programme de suivi par tests en laboratoire pour vérifier les conclusions provisoires tirées des résultats obtenus en installation-pilote.

Avant d'effectuer d'autres tests en installation-pilote, on devrait évaluer le mérite économique du procédé RIP en utilisant partiellement les renseignements obtenus au cours des programmes de la phase I et de la phase II. On recommande l'exécution d'une étude de factibilité technique pour examiner les estimations des frais d'exploitation et coûts d'investissement pour le processus résine/pulpe, et comparer ces données économiques à celles correspondant au processus carbone/pulpe qui est fréquemment utilisé commercialement. En l'absence de renseignements sur la conception confirmés par les opérations en installation-pilote, on peut coupler les mesures cinétiques comparatives sur la résine et le carbone avec les techniques de modelage mathématique disponibles. Cette simulation du procédé de traitement peut générer le nombre d'étages, la concentration et le chargement de la résine, et les niveaux d'or à l'état stationnaire dans la résine et la solution. Les résultats de l'étude de factibilité permettront de déterminer si d'autres travaux en installation-pilote sont économiquement justifiés.

Si les résultats indiquent qu'il convient d'effectuer d'autres travaux en installation-pilote, on recommande l'exécution d'un programme détaillé d'évaluation de la résine avant la planification de la campagne en installation-pilote. On devrait effectuer ceci en utilisant un lot important de la résine expérimentale.

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2.0 INTRODUCTION

Most of the recently discovered Canadian gold ore deposits contain finely disseminated gold, resulting in a liberation size typically finer than 200 mesh. Since liquid-solid separation at fine particle sizes is costly, it is advantageous to recover the gold directly from the pulp. Therefore, adsorption technologies such as carbon-in-pulp (CIP) or resin-in-pulp (RIP) are very attractive.

While carbon-in-pulp technology is being used by many gold mills, resin-in-pulp remains in development. Although this novel technology has been investigated in South Africa, with the exception of the current test program, no work has been reported to date using Canadian gold ores.

In March of 1985, Witteck Development submitted an unsolicited proposal to the Department of Supply and Services (DSS) and Canada Centre for Mineral and Energy Technology (CANMET) entitled "Evaluation of Resin-in-Pulp for Canadian Gold Ores". The proposal outlined a three-phase test and feasibility program encompasing the following:

Phase I Development of benchscale RIP data using authentic gold mill solution and pulp.

Phase II Pilot demonstration of the RIP process using a typical Canadian CIP feed slurry.

Phase III An engineering feasibility study including process flowsheet, order-of-magnitude capital and operating costs and a technical comparison of RIP and CIP.

A contract was awarded for Phase I (DSS Contract 14SQ.23440-5-9093) which was completed August 29, 1986. The key results of the benchscale testwork completed during Phase I are summarized below.

- An experimental resin was evaluated which demonstrated a distinct selectivity for gold over most of the common base metals (zinc was the only base metal found to load to any extent during Phase I.)

- The gold-loading capacity of this resin in a RIP process was comparable to that obtained by the originating mill using CIP (10.5 kg/t or 300 oz/t).

- Gold was recovered efficiently from the resin using a method commonly used for gold desorption from carbon.

Due to these encouraging Phase I results, a proposal for Phase II was submitted to DSS and CANMET and a contract was awarded on October 27, 1986. The testwork for Phase II has been completed and is reported herein.

3.0 FEED MATERIAL

3.1 Gold-Bearing Pulp

The gold-bearing pulp was received from Teck-Corona, Hemlo mine. In total, 120 drums of slurry was cut from the feed to the carbon-in-pulp circuit over a ten hour period during March 12 and 13, 1987. Since the retention time in the cyanidation leach circuit at Teck-Corona is six hours, the pulp composition varied somewhat over the filling period. Solution composition data obtained from Teck-Corona at the time the slurry was taken from the circuit is provided in Table 1.

Table 1

FEED SOLUTION COMPOSITION

Drums	pH	Gold		CN(F)*, mg/L
		oz/ton	mg/L	
1 to 30	10.2	0.182	6.24	50
31 to 60	10.1	0.184	6.30	50
61 to 90	10.1	0.184	6.30	65
91 to 120	10.4	0.186	6.39	60

*CN(F) = Available cyanide as determined by silver nitrate titration. See Appendix IV - Analytical Procedures.

The drums were shipped on March 16 and 17 and were received by Witteck Development on March 19 and 20, 1987.

Three drums of the pulp were opened on March 19 to enable characterization of pulp prior to startup. The feed slurry contained 49.5% solids (pulp density= 1.41 kg/L). Screen analysis of the pulp, provided in Table 2, indicates that the pulp was 77 percent minus 200 mesh.

Table 2

SIZE DISTRIBUTION OF FEED PULP

Mesh Size	Cumulative % Passing
150	98.4
200	76.9
325	49.8
400	48.7

Chemical analysis of the pregnant slurry filtrate is provided in Table 3.

Table 3

ANALYSIS OF FEED PULP FILTRATE

Element	Au	Ag	Cu	Fe	Ni	Zn
Assay, mg/L	6.52	0.53	6.6	10.6	0.36	0.60

The pH of the as-received pulp was 9.7 and the level of available cyanide was 0.04 g/L.

The feed pulp was used as received; no preliminary preparation nor adjustment of the pulp was required prior to start-up. However, the pilot plant circuit included a repulp tank (see Section 5.0) where reagent additions (e.g. cyanide, lime) were carried out as part of the resin-in-pulp circuit.

3.2 Resin

Three shipments of the experimental resin XU-40114.00 were supplied by Dow Chemical. Since the resin characteristics varied somewhat from batch to batch (see Section 4.0, Preliminary Resin Testwork), the resins received are classified in Table 4 according to synthesis batch, as provided by Dow, and date received by Witteck Development.

Table 4

SAMPLES OF XU-40114.00 RESIN
RECEIVED FROM DOW CHEMICAL DURING 1987

Synthesis Batch	Volume Received	Date Received
A	10 L	February 13, 1987
B	1 L	March 6, 1987
	1 L	March 18, 1987
C	2 L	March 18, 1987

Since the XU-40114.00 resin was a weak base resin, its loading capacity was directly dependent upon the pH of the solution or pulp with which it is in contact. Therefore, prior to use, the resin was soaked overnight in pH 10 lime water to ensure complete swelling of the resin beads, and to convert the resin to the equilibrium mixture of free base and acid forms present at the natural pH of the gold-bearing slurry (see Section 3.2 of Phase I report for a description of weak-base resins).

After the swelling was complete, a sample of the first shipment received (Resin A) was subjected to a screen analysis; the results are provided in Table 5.

Table 5

SCREEN ANALYSIS OF RESIN A

Mesh Size	Volume mL	Volume %	Cumulative % Retained
10	0	0	0
20	8	1.5	1.5
28	435	83.7	85.2
35	50	9.6	94.8
48	26	5.0	99.8
-48	1	0.2	100.0
Total:	520	100.0	

Although 85% of the resin was plus 28 mesh, a large percentage of the plus fraction was observed to fit in the 28 mesh screen pores, effectively plugging the screen. Therefore, in order to reduce both the plugging of the interstage screens and loss of resin through the resin-in-pulp circuit, the resin was prescreened to 100% plus 32 mesh.

Prior to startup, the plus 32 mesh resin A was batch loaded with zinc cyanide, $Zn(CN)_4^{2-}$, and stripped in order to avoid the use of "fresh" resin during the pilot campaign. Zinc cyanide was chosen since it was the only base metal cyanide complex which was observed to load competitively with gold cyanide during the Phase I benchscale studies. Gold cyanide was not used in order to avoid having residual gold on the resin prior to startup.

Resin samples B and C were soaked in pH 10 lime water and prescreened to 100% plus 32 mesh without prior screen analysis. These subsequent resin samples were used without prior loading/elution of zinc cyanide.

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4.0 PRELIMINARY RESIN TESTWORK

Upon receipt of the first resin shipment (Resin A, 10 L received February 13, 1987), preliminary resin evaluation tests were carried out to confirm both the adsorption and the elution characteristics of the XU-40114.00 resin. Since this was an experimental resin, and each batch was synthesized individually on a benchscale basis by Dow Chemical, there was a need to confirm the consistency of the resin characteristics from one batch to the next.

4.1 Adsorption Characteristics

Originally, Witteck Development had requested 10 litres of 10 to 16 mesh resin from Dow Chemical Inc. The large mesh size would greatly ease the resin/pulp separation process during pilot operations. Although 50 mesh resin had been used during the Phase I benchscale program, a Dow representative had indicated that there would be little variance in resin adsorption capacity or gold selectivity with the larger bead size. However, the kinetics of adsorption/elution might be slower with larger resin beads.

Unfortunately, Dow could not produce the 10 to 16 mesh resin prior to startup. On February 13, 1987, 10 L of 30 to 50 mesh XU-40114.00 resin was received (see Section 3.2 for screen analysis). The resin was prescreened to 100% plus 32 mesh, resulting in rejection of approximately 15% of the resin. Since this reduced the quantity of resin available for the pilot campaign, it was decided to carry out the preliminary resin adsorption confirmation testwork using the rejected minus 32 fraction. As mentioned above, it was anticipated that mesh size alone would affect the kinetics of adsorption, but not the equilibrium loading capacity.

The equilibrium loading capacity test was carried out on a benchscale basis by agitating the resin with the pulp (1 mL of resin per litre of pulp) for 24 hours. The resin was recovered by screening and was contacted with a further aliquot of fresh pulp. This was repeated for four contact stages in total.

Similarly the pulp recovered from the first 24 hour contact was contacted with a second aliquot of fresh resin.

The results of the adsorption test are presented in Figure 1. The head pulp contained 6.64 mg of gold per litre of filtrate. After four stages of contact, the resin was loaded to 9.8 g Au/L of resin. This is somewhat less than the maximum equilibrium loading capacity; after the final contact, the gold level in solution had decreased from 6.64 mg/mL to 6.09 mg/mL, indicating that the resin had capacity remaining.

After two contacts with fresh resin, the gold level of the treated pulp was 0.08 mg/L in solution.

Therefore, for the pilot plant demonstration, it was assumed that resin loadings of 10 g Au/L could be anticipated with the 1987 resin A sample and the fresh Teck-Corona pulp. This is in agreement with the targeted 10 g/L loading predicted on the basis of the Phase 1 testwork, and on which the original program plan was designed (see Appendix 1, Program Plan).

During the loading capacity test, kinetic samples were removed from the first contact after 2, 4, 6, 7.5 and 24 hours. Since the resin used was 100% minus 32 mesh, the results should have provided an indication of the kinetic variance with mesh size when compared to the Phase 1 results which used 100% plus 50 mesh resin. The results are presented in Figure 2.

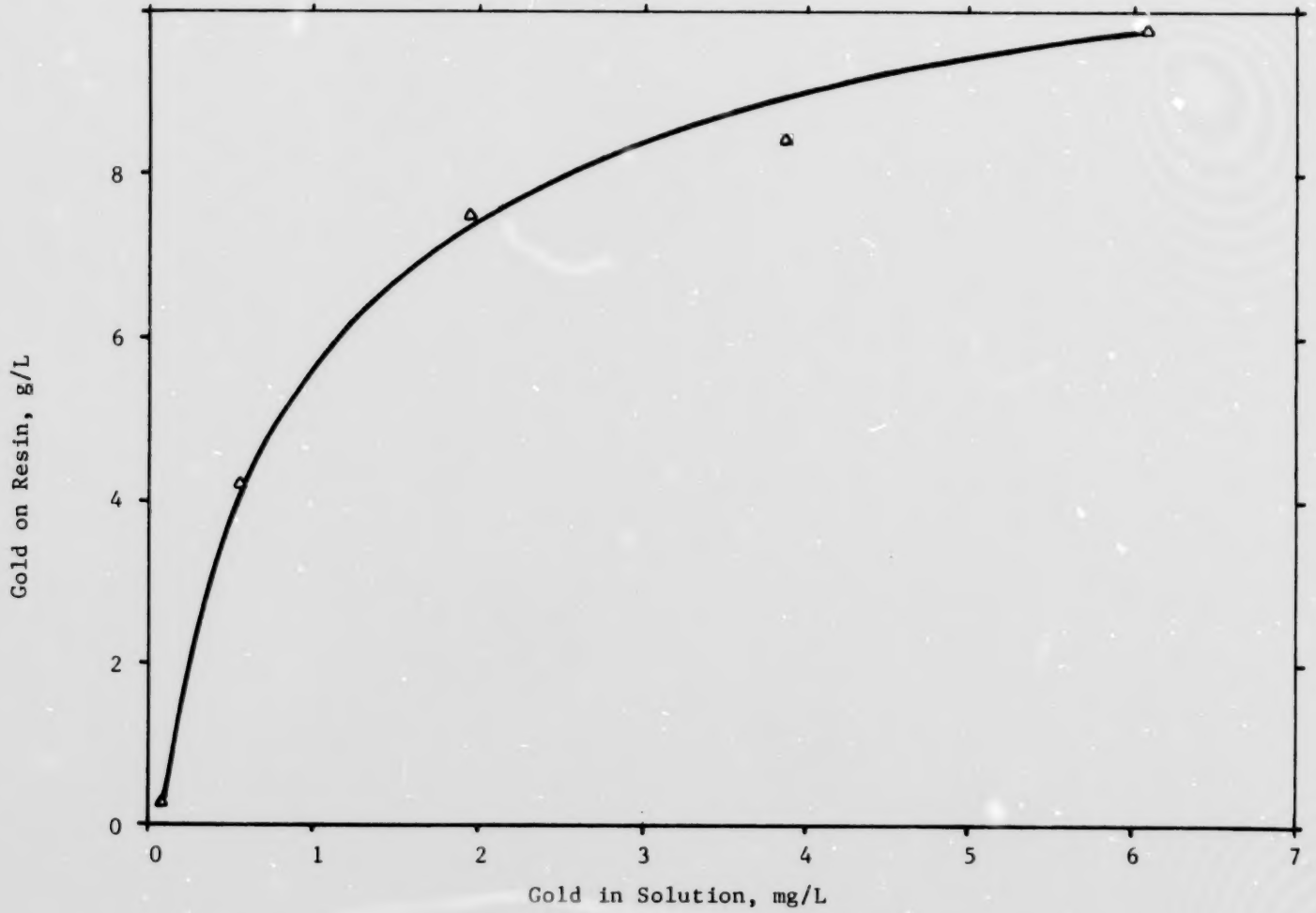

FIGURE 1: EQUILIBRIUM ADSORPTION ISOTHERM FOR RESIN A

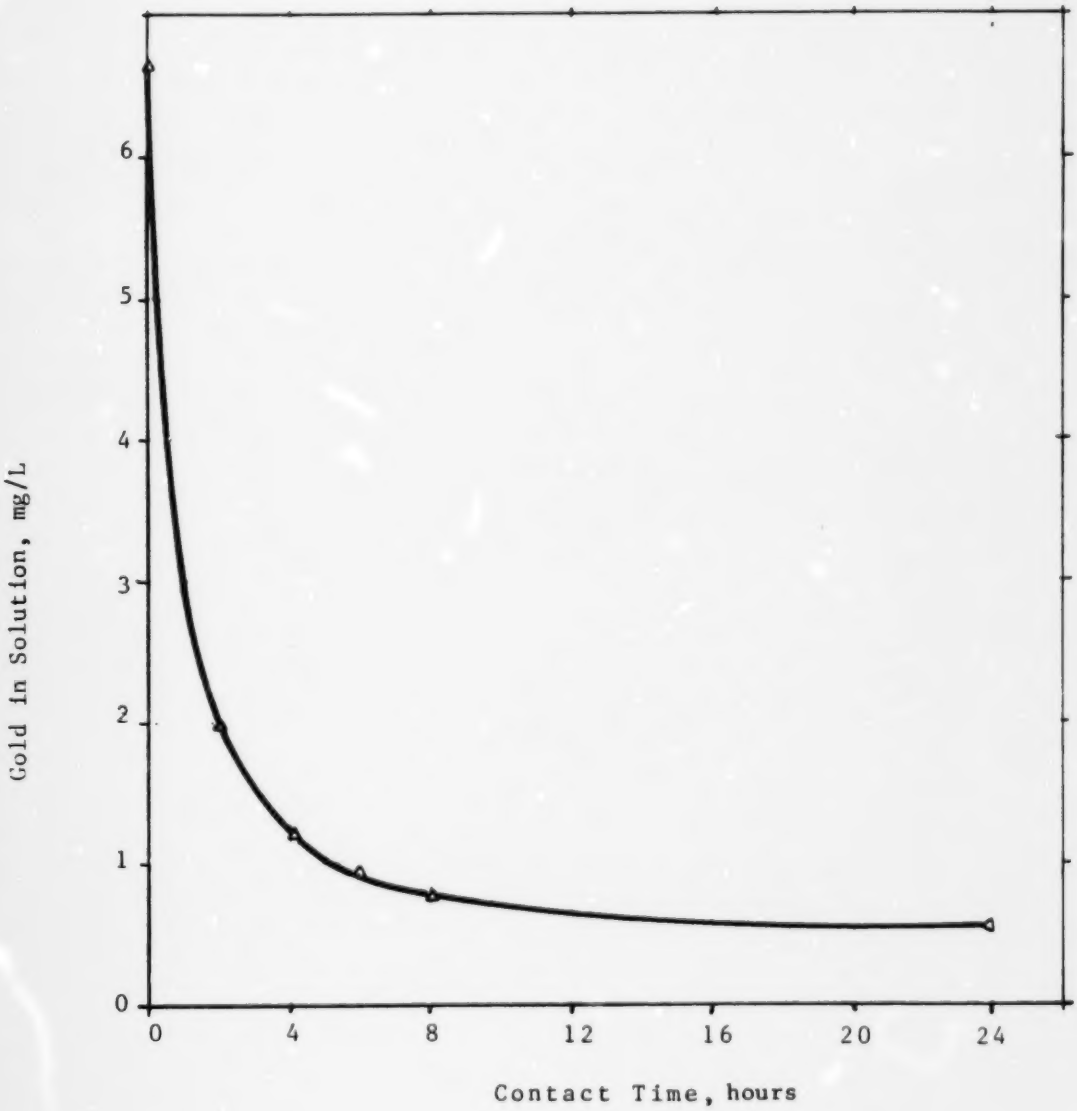

FIGURE 2 : ADSORPTION KINETICS FOR RESIN A

After the first 24 hour equilibrium contact, gold in solution was reduced from 6.64 to 0.54 mg Au/L; the resin loading was 4.2 g Au/L resin. After the first 2 hours, the gold in solution was reduced to 1.98 mg/L, indicating that 76% of the 24 hour one-stage equilibrium loading capacity was achieved within the first 2 hours of contact. This is 8% higher than the 68% observed during Phase I using 100% plus 50 mesh resin. As anticipated, the undersize fraction used in the current test program did show somewhat faster adsorption kinetics.

4.2 Elution Optimization

In addition to confirming the general elution performance of resin, (i.e. elution kinetics and required number of bed volumes) additional elution tests were carried out in an attempt to optimize the elution procedure itself.

The procedure which had been developed during Phase I utilized an eluant consisting of 1% NaCN, 1% NaOH maintained at temperatures between 90 and 93°C (i.e. similar to the Zadra method for carbon desorption). Although this eluant performed well during Phase I (98% of the gold was eluted from the resin within 15 bed volumes) there was concern as to the physical and chemical stability of the resin at such elevated temperatures. The XU-40114.00 resin is a weak base resin. Therefore, its functional groups would be inactive at pH levels above the pKa of the resin (See Section 3.2, Phase I report for description of weak base resins). Therefore, the resin should be readily eluted at high pH. The elution optimization testwork consisted of determining if similar elution performance could be obtained by using lower temperatures in conjunction with higher levels of NaOH.

Nine elution tests were carried out. In all cases, the resin was loaded using a synthetic aurocyanide solution. A summary of both the experimental conditions and the results is provided in Table 6. Since elution performance, with the exception of kinetics, was not expected to be affected to any great extent by mesh size, these tests were performed using the minus 32 mesh screen fraction in order to reserve the plus 32 mesh fraction for the pilot campaign.

Table 6

RESULTS OF PRELIMINARY RESIN ELUTION TESTWORK

Test	Resin Sample	Au Loaded, g/L resin	Eluant			Gold Eluted	
			NaOH	NaCN	Temp. °C	%	B.V.
1	1986	1.0	1%	1%	90-93	14	2
2	A	1.0	1%	1%	90-93	<1	2
3	A	1.7	1%	1%	90-93	<1	2
4	A	1.0	1%	1%	20	<1	2
5	A	1.0	5%	1%	20	<1	2
6	A	1.0	10%	1%	20	<1	2
7	A	1.0	10%	10%	90-93	2.6	2
8	A	10.7	1%	1%	90-93	20	2
9	B	5.9	1%	1%	90-93	32	2
10	B	8.8	10%	1%	20	2	2

For the first seven tests, the resin was loaded to less than capacity (i.e. 1 to 2 g Au/L resin). The objective of the first three tests was to confirm that the new resin sample (Resin A, received February 13, 1987) was comparable to the 1986 resin which was used during Phase I with respect to elution performance. Under test conditions (1 g Au/L resin, 1% NaOH, 1% NaCN, 90 to 93°C) a fresh sample of the 1986 resin eluted 14% of the gold in two bed volumes of the 1% NaOH, 1% NaCN, 90 to 93°C eluant.

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However, less than 1% of the gold was recovered from the new resin shipment (resin A) under identical conditions (tests 2 and 3, Table 6), indicating that the resin received for the pilot plant campaign displayed poorer elution characteristics than the 1986 resin sample.

Concurrently, four elution optimization tests were performed (Tests 4 to 7) using the same eluant (1% NaOH, 1% NaCN) at ambient temperature (20°C, Test 4), as well as higher levels of caustic (Tests 5 and 6) and higher levels of caustic and sodium cyanide at elevated temperatures (Test 7). In all cases, poor gold recoveries were observed in the first two bed volumes.

Finally, one test was carried out at higher gold loadings. Resin A, loaded to 10.7 g Au/L of resin, was found to elute 20% of the gold in two bed volumes, far below the typical recoveries observed during the Phase I testwork at comparable resin loadings.

These results were presented to Dow Chemical and on March 6, a 1 L sample of a different synthetic batch of resin (resin B) was received by Witteck for elution evaluation tests. As indicated by the results of Test 9, resin B, loaded to 6.9 g/L, eluted 32% of the gold in 2 bed volumes, under standard conditions (1% NaOH, 1% NaCN, 90 to 93°C) indicating improved performance over resin A. However, in a further attempt to elute at lower temperatures (Test 10), only 2% of the gold was eluted at ambient temperatures using 10% NaOH and 1% NaCN.

The above results indicate that elution at ambient temperature was far less efficient than at elevated temperatures. Witteck and CANMET decided to proceed with the high temperature elution procedure and to investigate, during the pilot plant operation, how resilient the resin was to high temperature elution.

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The original 10 L resin sample (resin A) was rejected in favour of resin B. Dow Chemical agreed to send one additional litre of resin B and to synthesize two additional litres of resin in time for start-up of the pilot campaign. The third resin shipment, received March 18, 1987, contained 3 litres of resin in total, 1 L of resin B and 2 L of resin C. Dow indicated at the time that, based on resin specifications, resin C would most likely display elution characteristics between those displayed by resin A and resin B. Therefore, it was understood that the campaign would proceed with less than optimal resin quality with regards to the elution cycle.

5.0 PILOT PLANT CIRCUIT AND OPERATION

As intended by the original three-phase proposal, the Phase II pilot plant design criteria were based on the adsorption and elution characteristics of the resin established during the Phase I benchscale testwork and the preliminary testwork conducted during Phase II. Appendix B describes the assumptions and the basis on which the original design criteria were established. Prior to startup, a detailed program plan was prepared which listed the design criteria, as well as the material requirements and preparation, circuit description, operating parameters and procedures, and a preliminary sampling schedule.

The detailed program plan is provided in Appendix A. A brief description of the pilot plant circuit and operation is provided below.

5.1 RIP Circuit Description

With few exceptions, the RIP circuit was set up as described in the original program plan (Appendix A). The flowsheet of the operation is presented in Figure 3. Photographs of the pilot plant are provided in Figures 4 to 6.

The as-received feed material was repulped and prescreened through a 65 mesh Sweco screen to remove tramp and oversize material. The screen underflow was pumped to a 1300 L conditioning tank which was designed to provide sufficient feed for 24 hours of operation. Lime and sodium cyanide were added as required to adjust the feed pulp to between pH 9.8 and 10.2 and the cyanide level to 0.2 g/L available cyanide (as determined by silver nitrate titration). After each addition of NaCN the pulp was agitated for at least 1 hour to ensure complete solubilization of the gold.

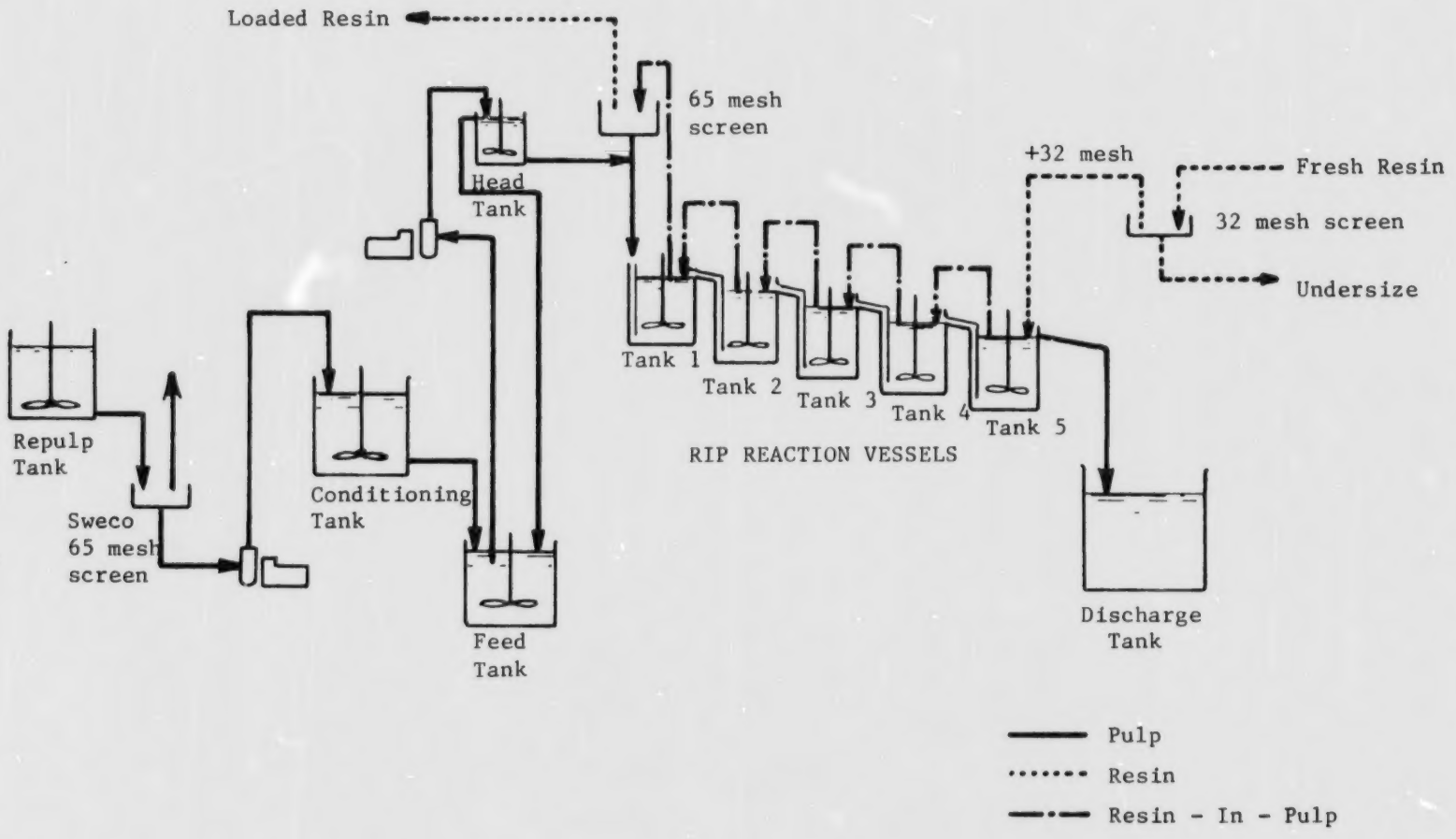

FIGURE 3: RESIN - IN - PULP CIRCUIT DIAGRAM

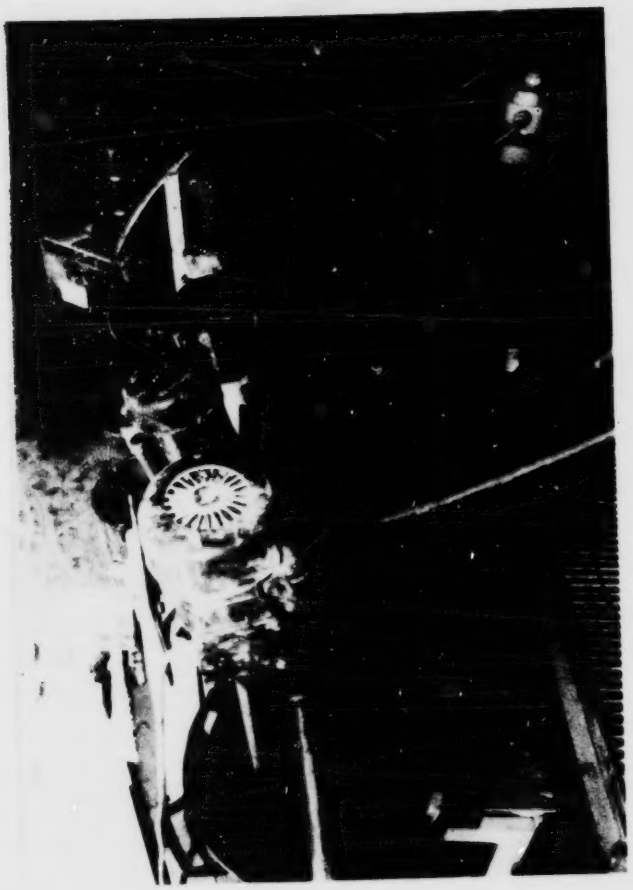

Figure 4: Top-view of Five stage RIP circuit. Repulp tank (orange) and 1300 L conditioning tank are shown at rear of RIP circuit. Tubes to head tank are shown at far right of photograph

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Figure 5: Side-View of RIP Circuit, showing:
repulp tank (orange, left), 1300 L conditioning tank (blue)
feed tank (black), part of Sweco screen (silver, behind black
feed tank) and discharge tank (orange, centre)

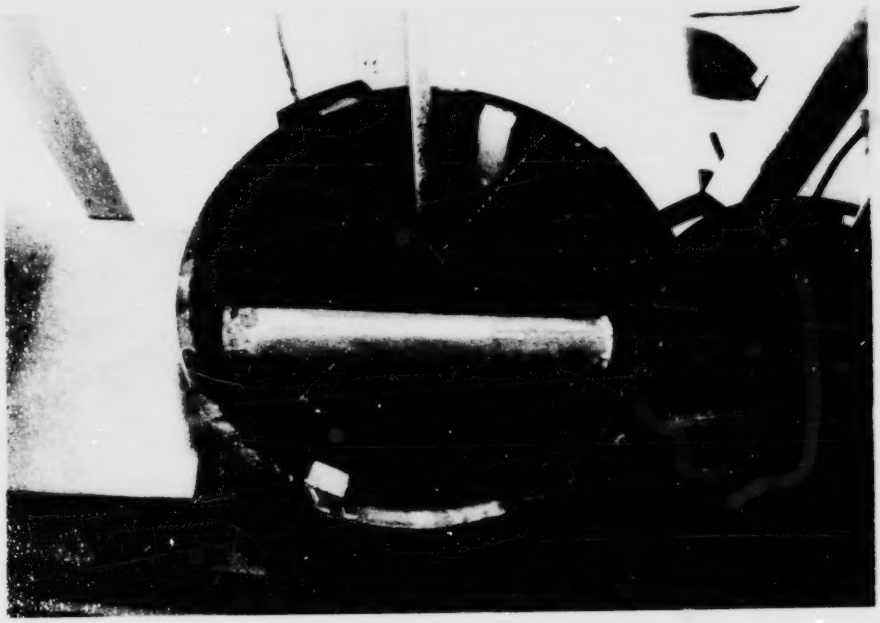

Figure 6: Close-up of one stage of RIP ciruit
showing agitator, single axial-flow impeller, 2 baffles,
downcomer for incoming slurry and overflow launder
constructed of 48 mesh screen material
with steel supports

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The conditioned feed pulp was fed periodically to the feed tank by gravity flow. A recirculating pump provided a constant flow of pulp from the feed tank to a 20 L head tank. The head tank was equipped with an overflow tube to the feed tank, and provided a constant head of pulp for gravity flow to the RIP reaction vessels.

The pulp was contacted with the resin in a series of five agitated vessels arranged in cascade. The barren pulp discharged the RIP train into a 200 L drum.

Resin was advanced countercurrently to the pulp flow every 30 minutes. This was carried out manually by transferring the required volume of pulp with its entrained resin upflow one stage, beginning with Tank 1. The loaded resin was recovered from the Tank 1 pulp by screening (65 mesh). Fresh or eluted resin was added to Tank 5.

5.2 RIP Circuit Operation

5.2.1 Operating Parameters

After the initial startup/shakedown period (20 hours) steady operation was established. Two sets of operating parameters were tested. Run 1 lasted 82 hours from 20 hours to 102 hours; Run 2 lasted 106 hours from 102 hours to 208 hours at shutdown. The operating parameters for these two periods of operation are summarized in Table 7.

5.2.2 Operating Procedures

The pulp density of the feed and discharge slurries was measured every 2 hours, to ensure that solids were not building up within the RIP tanks (i.e. only the resin was being retained by the interstage screens).

Table 7

SUMMARY OF PILOT PLANT OPERATING CONDITIONS

Parameter		Run 1	Run 2
Number of Stages		5	5
Volume per Stage	,L	54	54
Pulp Flow Rate	,L/h	27	9.3
Retention Time per Stage	,h	2	5.8
Solution Feed Rate	,L/h	19.2	6.6
Gold Conc. in Solution	,mg/L	5.96	6.23
Gold Flow	,mg/h	114.4	41.1
Design Resin Loading,	,g/L	9.5	3.4*/2.1**
Resin Flow	,mL/h	12	12*/20**

* fresh resin

** eluted, recycled resin

The pH of the feed and discharge slurries was measured every two hours, since pH is the most important control parameter for the adsorption of anions using weak base resins (see Phase I report, Section 3.2 for a description of weak base resins).

The pulp feed rate to Tank 1 was recorded every hour. In addition, the volume of pulp contained in every drum of pulp opened was noted, as was the volume of every drum of barren pulp discharged from the RIP circuit.

The total amount of resin added to and recovered from the circuit during the 10-day campaign was recorded.

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5.2.3 Sampling Schedule

Daily composites were collected from six sampling locations, the feed pulp and the discharge streams from the overflow launders of Tanks 1 to 5. The filtrates were assayed for gold. In addition, the feed and Tank 5 discharge filtrates were assayed for zinc (note: zinc was the only base metal observed to load on the resin to any significant extent during Phase I). Occassionally, the feed and Tank 5 discharge solids were assayed for gold to ensure that gold was not precipitating or being leached within the RIP circuit. Finally, to investigate the behaviour of all metals of interest, campaign composites of the feed and discharge filtrates were assayed quantitatively for Sb, As, Co, Cu, Fe, Ni, Ag and Zn and were assayed semi-quantitatively for Cr, Pb, Mn, Hg, and Mo.

5.3 Resin Elution Procedures and Sampling Schedule

The loaded resin was collected and composited on a daily basis. A sample of the loaded resin daily composite was assayed for gold and zinc. A second sample was added to a 10-day composite.

The remaining resin was eluted batchwise by contacting the resin with eluant, one bed volume at a time for 30 minutes. The eluant consisted of 1% NaOH and 1% NaCN, maintained at 90 to 93°C. After each contact, the resin was recovered and rinsed with approximately one bed volume of 1% NaOH at 85 to 93°C. The eluate and wash for each contact were combined and assayed for gold. For each resin daily composite, all eluate bed volumes were composited and assayed for Sb, As, Co, Cu, Au, Fe, Ni, Ag and Zn.

After 12 bed volumes of eluate had been contacted with the resin, the eluted resin was assayed for gold and zinc and a sample was added to a 10-day composite.

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Ten-day composite samples of both the loaded and eluted resin were assayed quantitatively for Sb, As, Co, Cu, Fe, Ni, Ag and Zn and were assayed semi-quantitatively for Cr, Pb, Mn, Hg, and Mo.

6.0 PILOT PLANT RESULTS AND DISCUSSION

The pilot plant was operated for a total of ten days, from March 24 to April 2, 1987. The results are presented and discussed below for the resin-in-pulp circuit (Section 6.1) and the elution circuit (Section 6.2), respectively.

6.1 Resin-In-Pulp

6.1.1 Operational Results

The resin-in-pulp circuit began operations at 1600 hours on Day 1 (March 24, 1987). The pilot plant circuit, operating parameters and sampling schedule have been described in Sections 5.1 to 5.3.

During the 20 hour startup period, the amount of agitation provided by the pilot plant contactors was investigated to ensure that homogeneous mixing was occurring. Large pulp samples were removed from the tanks and screened to determine the resin content. The rate of rotation of the impellers was increased until samples removed consistently contained 1.39 mL of resin per litre of pulp.

The as-received feed pulp was checked for pH and available cyanide on a twice-daily basis. The pH of the as-received pulp varied from 9.4 to 10.3. This was adjusted as required to pH 9.8 and 10.3 by the addition of lime to the 1300 L conditioning tank. The available cyanide level of the as-received pulp was very low, ranging from 0.04 to 0.14 g/L in the filtrate. This was adjusted to 0.2 g/L available cyanide by the addition of sodium cyanide to the conditioning tank after each addition of fresh pulp to the tank. After each pulp/sodium cyanide adjustment, the feed line from the conditioning tank to the feed tank was closed, and the adjusted pulp was agitated for 1 hour to ensure complete solubilization of precipitated gold.

The pulp feed stream to Tank 1 of the RIP circuit and the discharge stream from Tank 5 were checked every 2 hours for pH and pulp density. The range of pH and average pulp density across the RIP circuit for both runs of the pilot program is provided in Table 8.

Table 8

pH RANGE AND AVERAGE PULP DENSITIES

Sample	pH Range	Average Pulp Density, g/L
Feed	9.6 to 10.4	1428
Discharge	10.0 to 10.5	1421

The constant pH range ensures that the weak-base resin will be operating within the pH range most common for commercial carbon-in-pulp circuits. The pulp densities did not decrease across the circuit, indicating that solids were not accumulating in the RIP tanks due to the retention by the interstage screens.

In order to ensure that neither gold precipitation nor gold dissolution was occurring during the gold recovery process, one set of daily feed and discharge samples, as well as the corresponding 10-day composite samples, were filtered and the solids were assayed for gold. The results are provided in Table 9.

Table 9

GOLD LEVELS IN FEED AND DISCHARGE SOLIDS

Sample	Gold in Solids, g/t	
	Feed	Discharge
Daily Composite (Day 7)	0.29	0.27
10-Day Composite	0.30	0.20

Although the daily composite indicated no change in the gold levels in the solids across the resin-in-pulp circuit, the 10-day composite samples did indicate that gold was dissolving. This may be attributed to either leaching of gold within the RIP circuit, or solubilization of gold which had precipitated during transportation and storage of gold-bearing pulp. In either case, the amount of gold dissolved during the resin-in-pulp process, 0.1 g/t, accounts for approximately 1% of the head grade (0.25 to 0.30 oz/metric tonne or 8 g/t gold).

The residual gold remaining in the solids, 0.2 to 0.3 g/t, is well within the acceptable range for tailings from Teck Corona's circuit; typical gold levels in the tailings are 0.5 g/t.

No operational problems were encountered. The prescreened pulp flowed readily through the 48 mesh interstage screens; the resin was retained. The interstage screens were never plugged or blocked by the resin beads. Although no resin was observed in the discharge pulp during Run 1, a small amount of resin was observed to exit the circuit near the end of Run 2. It was assumed that this was due to a small hole which developed in the Tank 5 interstage screen near the end of the 10-day campaign.

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6.1.2 Gold Recovery Performance

Run 1 (Days 2 to 5): After the initial 20 hour startup/shakedown period, Run 1 design operating parameters were achieved and maintained for 82 hours. As indicated in Table 7 (Section 5.2.2) Run 1 was operated at a pulp flowrate of 27 L/h (19.2 L/h of gold-bearing solution). At an average gold concentration of 6.0 mg/L during Run 1, the resin feed rate of 12 mL/h allowed for resin loadings of 9.5 g Au/L resin, close to the 10 g Au/L resin design parameter. According to both the Phase I testwork using the 1986 resin, and the Preliminary Testwork using Resin A (Section 4.1), this degree of gold loading was reasonable.

However, as mentioned in Section 4.2, the 10 L batch of resin A received for the pilot program was rejected following the results of the preliminary elution testwork. Consequently, Dow Chemical sent two additional resin samples, B and C, just prior to startup. One litre of resin B was received in time to confirm improved elution characteristics compared to resin A (see Section 4.2). However, due to planning and budget considerations, insufficient time remained to produce adsorption isotherms and kinetics for resins B or C, or to produce elution data for resin C prior to the firm startup date.

As only approximately 3 L of plus 32 mesh resin B and C was availale for the pilot operation, these two resin samples were mixed prior to start-up.

After the initial 20 hour startup/shakedown period, profile samples were taken every 2 hours of the pulp feed stream, and the RIP overflow launders from tanks 1 to 5. Although it had been intended originally to composite these samples over 8 hour periods, this was altered to a 24 hour composite schedule once

the initial data became available. The feed and discharge (Tank 5) samples were assayed for gold and zinc. The tanks 1 to 4 overflow samples were assayed for gold. The results are presented in Tables 10 and 11, respectively. Gold levels in the discharge filtrate are presented chronologically in Figure 7.

A spot check early in the morning of Day 2 after the design operating parameters were achieved, indicated that the gold in the discharge was 0.51 mg/L, well in excess of the 0.01 mg/L target level. Design conditions were maintained for 4 days (Days 2 to 5), during which the gold level increased steadily, reaching levels of 2.0 to 2.5 mg/L Au on Days 3, 4 and 5.

Table 10

FEED AND DISCHARGE SOLUTION ANALYSES,
DAILY COMPOSITES

		Solution Analyses, ppm			
		Gold		Zinc	
Run	Day	Feed	Discharge	Feed	Discharge
1	2	5.66	0.99	1.47	1.31
	3	6.34	2.03	2.56	2.76
	4	5.69	2.43	6.69	5.10
	5	6.00	1.93	5.02	4.17
2	6	5.98	0.66	6.52	1.64
	7	6.06	0.37	5.45	0.19
	8	6.29	0.40	11.7	0.57
	9	6.50	0.41	5.89	1.71
	10	6.51	0.11	14.8	1.80

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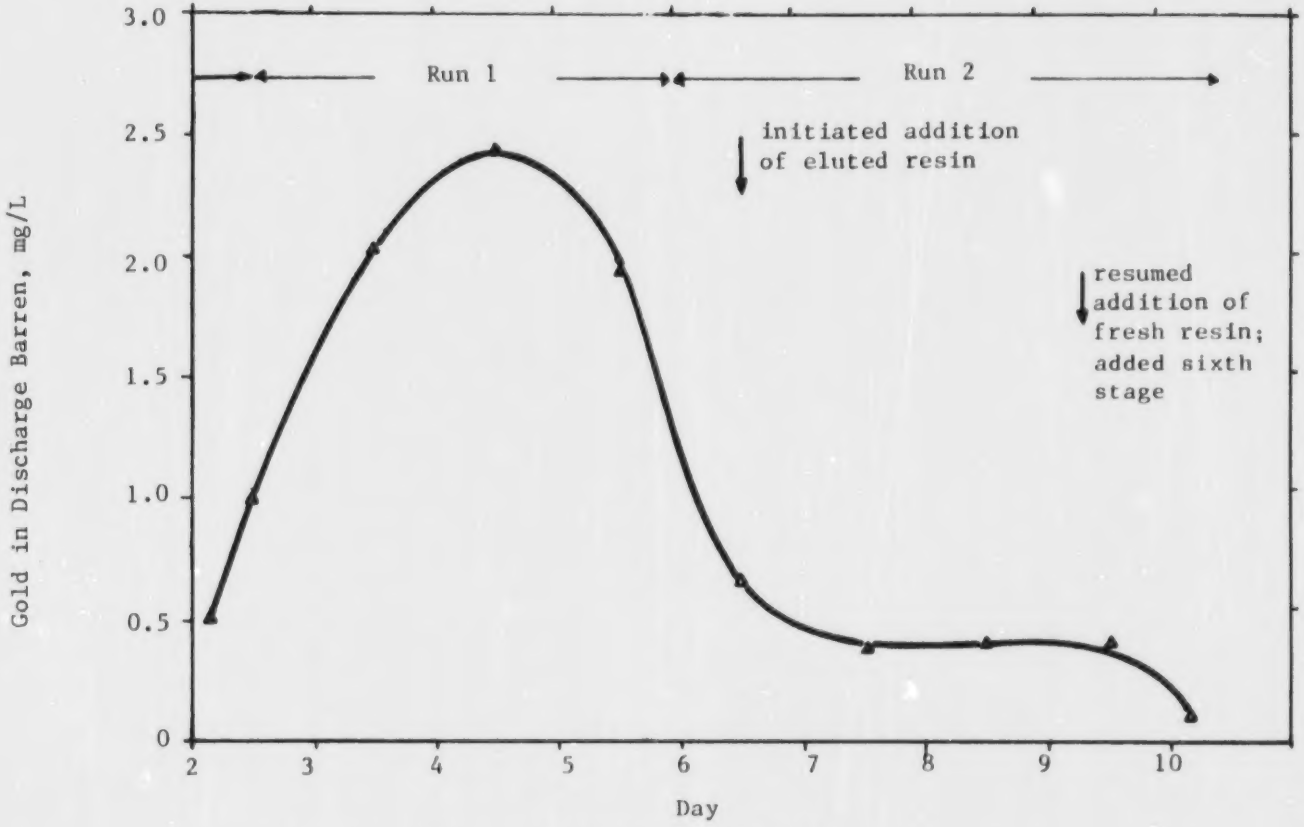

FIGURE 7: GOLD LEVELS IN BARREN PULP FILTRATE

Table 11

PROFILE SOLUTION GOLD ANALYSES

DAILY COMPOSITES

		Gold in Solution, ppm					
Run	Day	Feed	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5
1	2	5.66	5.17	4.04	3.00	2.13	0.99
	3	6.34	4.95	4.32	3.60	3.08	2.03
	4	5.69	5.77	5.31	4.53	3.48	2.43
	5	6.00	5.42	4.74	3.68	2.77	1.93
2	6	5.98	4.10	3.11	2.07	1.23	0.66
	7	6.06	3.41	2.15	1.11	0.64	0.37
	8	6.29	3.20	2.16	1.12	0.67	0.40
	9	6.50	3.49	2.27	1.33	0.72	0.41
	10	6.51	3.27	1.90	0.90	0.32	0.11

The three most likely reasons for the excessive levels of gold in the treated "barren" pulp were identified as:

- Insufficient resin to adsorb all of the gold (resin saturation)
- Resin was not gold-selective; part of the adsorption capacity was being consumed by base metal cyanide complexes.
- Insufficient resin/pulp contact in RIP tanks due to insufficient agitation or insufficient retention time.

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The first two reasons are possible if the untested resins B and C do not have the same adsorption capacity and gold selectivity as the resin samples received and tested previously. The last reason could result from the lower levels of agitation provided in the pilot plant contactors as compared to the excessive agitation provided by the benchscale equipment.

In order to quickly obtain information on the gold selectivity of the resin, a sample of the feed pulp was agitated with the resin B and C mixture in the laboratory, (1 mL of resin per litre of pulp). Samples were taken after 2 hours and the filtrates were assayed for Cu, Au, Fe, Ni and Zn. The results, presented in Table 12, confirmed that the resin was gold-selective.

Table 12

GOLD SELECTIVITY OF RESINS B AND C

	Analyses, mg/L				
Sample	Cu	Au	Fe	Ni	Zn
Feed	7.61	6.03	11.88	2.44	1.28
2 Hour	7.52	4.28	12.95	2.34	1.25

Run 2, Days 6 to 10: In order to address both of the remaining possibilities, it was decided to reduce the pulp feed rate, but maintain the same resin feed rate. This would improve both the resin to pulp feed ratio as well as the resin/pulp contact time. Since the resin gold loadings observed during Days 2 to 5 ranged from 5 to 6 g Au/L resin (see Section 6.2, Resin Analysis and Elution), approximately half of the target loading of 10 g Au/L resin, a reduction in the pulp feed rate by at least a factor of two was warranted. It was decided to reduce the pulp feed rate by a factor of three (27 L/h reduced to 9.3 L/h). The resin feed rate of 12 mL/h was maintained. This increased the pulp retention time from 2 h/stage to 5.8 h/stage.

The results of this parameter change were apparent immediately (Tables 10, 11 and Figure 7). The change was incorporated at 2200 h on Day 5. The daily composite sample of the discharge stream for Day 6 indicated a decrease in the gold level of the discharge barren from 1.9 mg/L to 0.66 mg/L gold.

As fresh resin supplies became depleted mid-day on Day 6, the recycling of eluted resin was initiated as planned. Due to the suspected reduced capacity of the eluted resin (see Section 7.1.3), the resin feed rate was increased from 12 mL/h to 20 mL/h concurrently. These operating conditions were maintained for 3 days, until 0800 h at Day 9. During this period of operation, the gold levels in the barren decreased to less than 0.5 mg/L gold. Once again, however, acceptable gold barren levels were not achieved.

In this case, the high gold barrens are attributed to the residual gold levels on the eluted recycled resin. Resin analyses (see Section 6.2) indicated that the "eluted" resin contained 1 g/L residual gold. Residual gold on the recycled resin would set-up an unfavourable equilibrium between gold in solution and gold in the resin, such that the resin could not adsorb the remaining 0.5 mg/L gold from the solution. Follow-up experiments (Section 7.1.1) indicated that the resin must be eluted to less than 0.06 g Au/L resin prior to re-use in order to achieve less than 0.01 mg/L gold in solution. Higher residual gold levels on the recycled resin would result in higher gold barren levels.

Consequently, there seemed little point in continuing to recycle the eluted resin to the RIP circuit.

The only fresh resin available was Resin A, which had been rejected originally due to its inefficient elution characteristics. However, its adsorption capacity was acceptable (Section 4.1). It was decided, therefore, to continue operations by adding fresh resin A to the circuit; the resin feed rate of 20 mL/h was maintained.

No further use would be made of recycled resin during this pilot program. As this would limit the attainment of a few of the program's objectives, (i,e, evalutation of long-term resin poisoning, resin scaling and resin attrition by recycling the resin many times), it was decided to continue operations only until acceptable gold barrens were achieved. Operations would then be ceased until such a time as sufficient quantities of elutable resin could be made available by Dow Chemical Inc.

In addition to adding only fresh resin, a sixth RIP reaction vessel was added to the circuit on Day 9. This tank was identical to the other five, but contained three times the resin inventory. The tank 5 discharge stream was allowed to flow through the sixth contactor prior to discharge from the circuit. The sixth tank was operated for the final 12 hours of operation. During this period, the Tank 5 discharge assayed 0.1 mg/L gold; the results for Tank 6 are presented in Table 13.

Table 13

TANK 6 DISCHARGE FILTRATES; GOLD ANALYSES

Time, h	0	1	2.3	4.5	8.5	12
Gold, mg/L	0.056	0.067	0.040	0.041	0.058	0.053

The results indicate that the sixth tank reduced the gold barren level from 0.1 to 0.04 mg/L gold.

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In Figure 8, a typical solution profile curve from Run 1 (Day 5) is compared to the solution profile curve from Day 10 of Run 2. The improvement in the adsorption profile (50% of the gold adsorbed in the first stage during Day 10 versus 10% during Day 5) is readily apparent.

Although barren levels (0.01 mg/L gold) might well have been attained during the second 10-day campaign, the reduced amount of information that would be obtained by operating with fresh resin only was considered insufficient when compared to the cost. Consequently, after discussions with CANMET, the second 10-day program was cancelled.

After shutdown, the 10-day composite samples of the feed and discharge filtrates were assayed quantitatively for Sb, As, Co, Cu, Fe, Ni, Ag and Zn and semi-quantitatively for Al, Cr, Pb, Mn, Hg, and Mo. The results, presented in Table 14, indicated that in addition to gold, cobalt, copper, nickel, silver and zinc were being removed from solution by the resin. This is in agreement with the results reported in Phase 1 with the exception of cobalt, which was not observed to load on the resin during the benchscale test program.

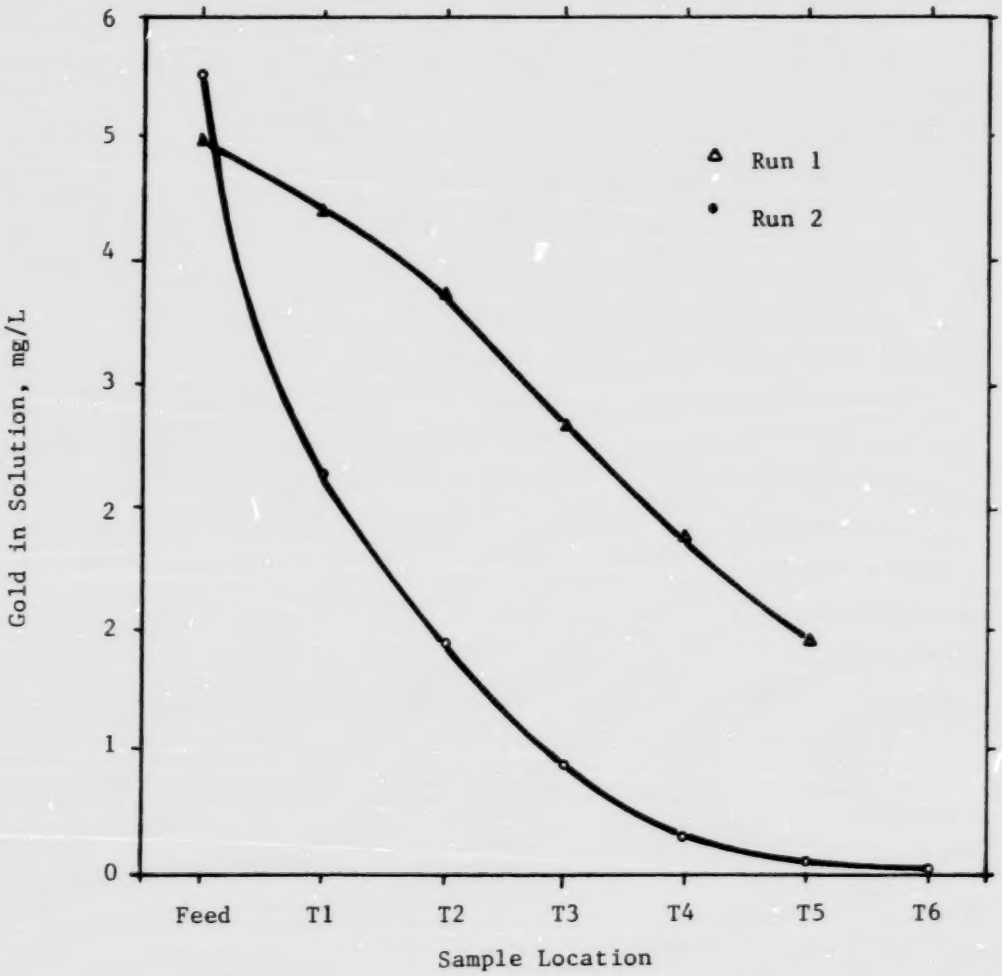

FIGURE 8: SOLUTION GOLD PROFILES; RUN 1 AND RUN 2

Table 14

ANALYSES OF FEED AND DISCHARGE PULP FILTRATES;
CAMPAIGN COMPOSITES

ELEMENT	ANALYSES, mg/L FEED	DISCHARGE
Aluminum	13.1*	15.0*
Antimony	9.07	9.69
Arsenic	0.02	0.07
Chromium	<0.001*	<0.001*
Cobalt	0.19	0.16
Copper	27.0	23.0
Iron	14.7	14.5
Lead	<0.001*	<0.001*
Manganese	0.03*	0.03*
Mercury	0.1*	0.1*
Molybdenum	4.3*	4.3*
Nickel	2.44	1.79
Silver	0.38	0.22
Zinc	8.61	2.08

*Performed by semi-quantitative multi-element analysis; gives order of magnitude only. All other analyses performed quantitatively.

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6.2 Resin Loading and Elution

Daily composite samples were prepared from the loaded resin recovered from Tank 1 of the RIP circuit. The volume of resin recovered was measured, the resin was washed once with water and a sample was submitted for gold and zinc analysis. A second sample was added to the 10-day composite. The remaining resin was eluted using the 1% NaCN, 1% NaOH eluant at 90 to 93°C, as described in Section 5.4. Each resin sample was contacted with a total of 12 bed volumes of eluant, except for the resin from Day 7, which was contacted with only 7 bed volumes of eluant. (At this point, resin elution was halted and fresh resin was fed to the circuit). The eluted resin was assayed for gold and zinc, and a sample was added to the 10-day composite.

The analyses of the daily loaded and eluted resin samples is provided in Table 15, along with the calculated percent recoveries for gold and zinc.

Table 15

RESIN ANALYSES, DAILY COMPOSITES

	Resin	Gold			Zinc		
	Volume	Analyses, g/L		%	Analyses, g/L		%
Day	mL	Loaded	Eluted	Eluted	Loaded	Eluted	Eluted
2	197	5.14	1.45	72	1.70	n.a.	-
3	264	6.04	1.64	73	n.a.	0.014	-
4	276	5.03	0.90	82	2.21	0.014	99.4
5	254	5.25	0.67	87	2.56	0.010	99.6
6	225	5.61	1.02	82	3.30	0.013	99.6
7	288	4.39	1.75	60	3.78	0.018	99.5
8	*	3.22	*	-	2.75	*	-
9	*	2.61	*	-	3.65	*	-
10	*	2.83	*	-	3.81	*	-

*Started feeding fresh resin to circuit on Day 9; ceased resin elution operation on Day 8.

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Gold levels on the loaded and eluted daily composite resin samples are presented chronologically in Figure 9. For Run 1 (Days 2 to 5), the resin gold loadings ranged from 5.0 to 6.0 g of gold per litre of resin, approximately half of the 10 g/L design loading. After the pulp feed rate was reduced from 27 L/h to 9.3 L/h for Run 2, the resin loadings decreased steadily as expected, reaching 2.6 g Au/L resin on Day 9.

Gold levels remaining on the eluted resin samples flucuated around the 1 g/L level. This is well in excess of the 0.06 g/L target level (Section 7.1.1) required to achieve less than 0.01 mg/L gold in the barrens upon recycle of the eluted resin.

Zinc elution was efficient. The resin was stripped consistently to less than 0.02 g of zinc per litre of resin; greater than 99% of the adsorbed zinc was removed from the resin within 12 bed volumes.

The gold was not eluted efficiently. Gold removal varied from 72% to 87% within 12 bed volumes, compared to the 98% in 15 bed volumes based on resin analyses observed during Phase 1.

The amount of gold recovered in each individual eluate bed volume is provided in Table 16. The percent gold eluted based on resin analyses (Table 15) is in good agreement with the percent gold recovered in the eluate samples. (Table 16)

Extrapolation of the elution data for the resin recovered from Days 2 to 6 (Table 16) indicated that on the average, a minimum of an additional 17 bed volumes, (30 bed volumes in total) would be required to achieve the 0.06 g/L residual gold target. Thirty bed volumes exceeded both the acceptable turnaround time for resin elution during the pilot plant

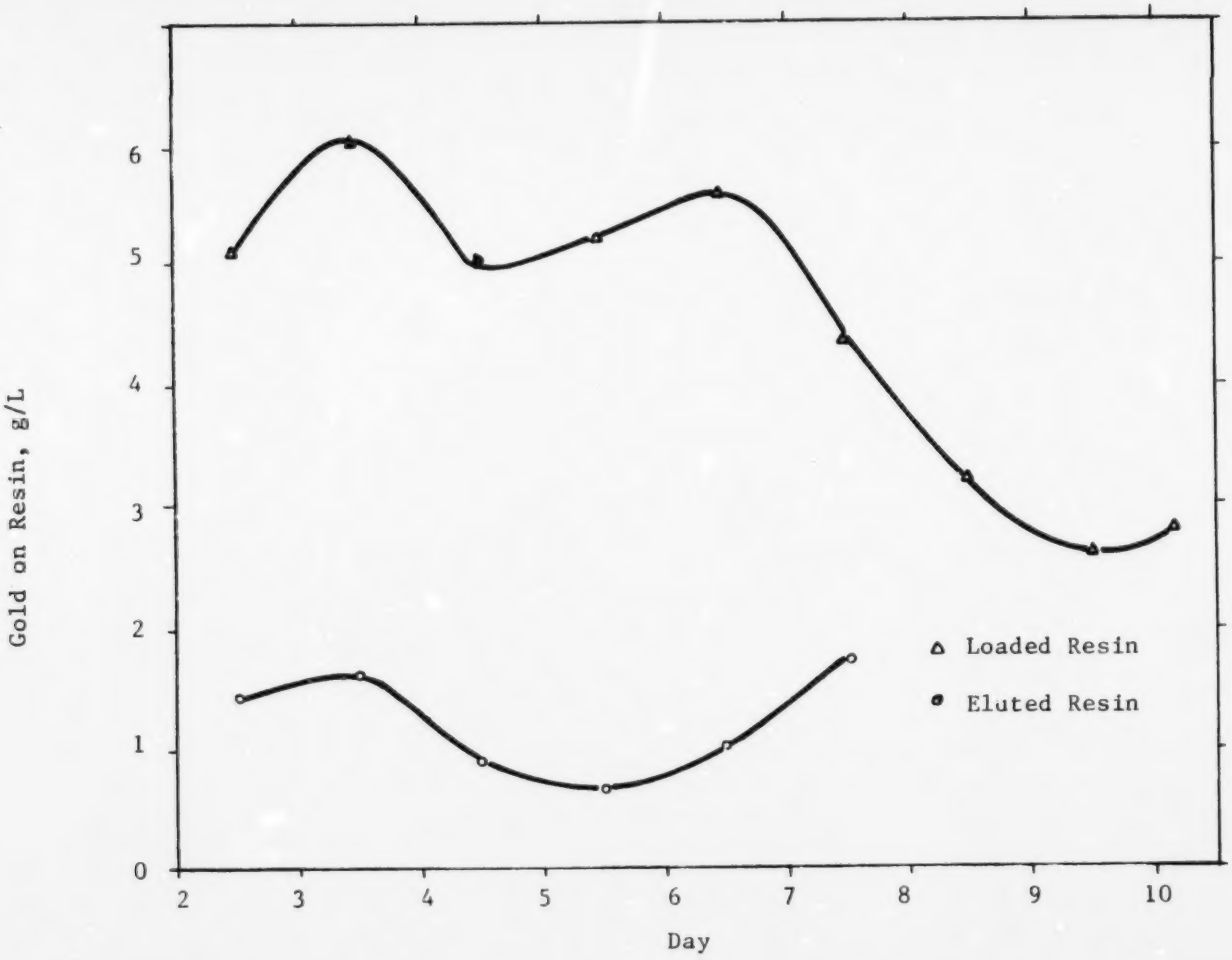

FIGURE 9: GOLD LEVELS ON LOADED AND ELUTED DAILY RESIN SAMPLES

operation, as well as typical bed volume requirements for commercial CIP circuits (10 to 15 bed volumes). Since acceptable barren would not be attained while recycling the partially eluted resin, resin elution and resin recycling were stopped on Day 9 and pilot plant operations were continued using fresh resin only.

Table 16

ELUTION OF LOADED RESIN DAILY COMPOSITES; ELUATE ANALYSES

Bed	Gold Recovered, mg					
Volumes	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
1	184.0	337.5	342.5	305.0	211.0	253.0
2	127.5	195.5	229.5	248.0	227.0	185.0
3	74.0	127.0	124.5	175.5	142.0	119.0
4	63.5	96.0	89.0	75.5	82.0	92.0
5	54.0	72.5	69.5	91.0	59.0	67.5
6	34.0	69.5	65.0	57.5	65.0	54.0
7	36.2	36.0	41.0	23.6	37.6	33.8
8	19.4	39.4	35.8	41.4	31.6	-
9	25.2	35.8	30.8	45.6	24.0	-
10	20.4	23.8	22.8	37.8	37.9	-
11	19.8	22.0	19.5	25.4	24.3	-
12	19.5	23.4	20.5	18.8	22.1	-
Total,mg	677.5	1078.4	1090.4	1145.0	963.6	804.3
Recovered	67%	68%	78%	86%	76%	64%

Daily composites were formed from the individual eluate samples. These were assayed for all other metals of interest. The results, provided in Table 17, indicate that in addition to gold and zinc, copper, iron, nickel and silver were present in the eluate, and therefore on the loaded resin. This is in

agreement with the data presented in the Phase 1 report, and Section 6.1, above. In addition, low levels of cobalt (0.5 mg/L) and trace levels of antimony and arsenic (0.05 mg/L) were present in the eluate samples.

Table 17

ANALYSES OF ELUATE DAILY COMPOSITES

	Amount Eluted, mg						% Recovered	
DAY	Cu	Au	Fe	Ni	Ag	Zn	Au	Zn
2	163	630	231	96	13.0	516	62	n.a.
3	n.a.	1020	n.a.	n.a.	14.3	641	64	n.a.
4	184	1062	133	55	9.6	547	76	90
5	n.a.	1170	n.a.	n.a.	10.7	641	88	99
6	203	966	347	90	13.0	777	77	105
7	n.a.	840	n.a.	n.a.	18.8	895	66	82

In order to ascertain the extent of the loading and which metals, if any, act as resin poisoning agents, the 10-day composite resin samples prepared from both the loaded and eluted daily resin composites were assayed for all of the metals listed above. The results, presented in Table 18, confirm that zinc was the only base metal found to load competitively with the gold. Copper, iron and nickel were adsorbed to the 0.5 g/L level. Silver and cobalt were present at low levels (0.05 g/L). Antimony and arsenic were below the detection limit. All metals which were adsorbed by the resin were eluted efficiently. These results are in agreement with the data reported in Section 6.1.

In summary, elution of gold from the resin was inefficient; zinc was eluted efficiently. All other metals which were observed to load to low levels (i.e. Cu, Fe, Ni, Ag and Co) were readily eluted. No resin poisoning agents were observed.

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Table 18

ANALYSES OF LOADED AND ELUTED RESINS; CAMPAIGN COMPOSITES

	Analyses, g/L	
Element	Loaded	Eluted
Antimony	<0.00004	<0.00004
Arsenic	<0.0002	<0.0002
Cobalt	0.04	0.02
Copper	0.52	0.004
Iron	0.65	0.03
Lead	<0.4*	<0.2*
Mercury	<0.4*	<0.2*
Nickel	0.37	0.03
Silver	0.047	0.004
Zinc	2.87	0.003

*Performed by semi-quantitive multi-element analysis; gives order of magnitude only. All other element performed quantitatively.

Since elution of gold was not a problem during the Phase I test program using the 1986 resin sample, it is assummed that the difficulty encountered was due to a variation at the resin synthesis stage.

Upon shutdown, the resin from each of the five resin-in-pulp tanks was recovered by screening. The resin was washed with water and assayed for gold. The results, along with the final solution profile analyses are provided in Table 19.

Table 19

FINAL GOLD PROFILES

Tank	Gold on Resin, g/L	Gold in Solution, mg/L
1	3.08	3.41
2	2.39	1.70
3	1.34	0.74
4	0.72	0.26
5	0.20	0.10
6	0.13	0.08

The data are presented in Figure 10, which displays the classical shape of an adsorption isotherm.

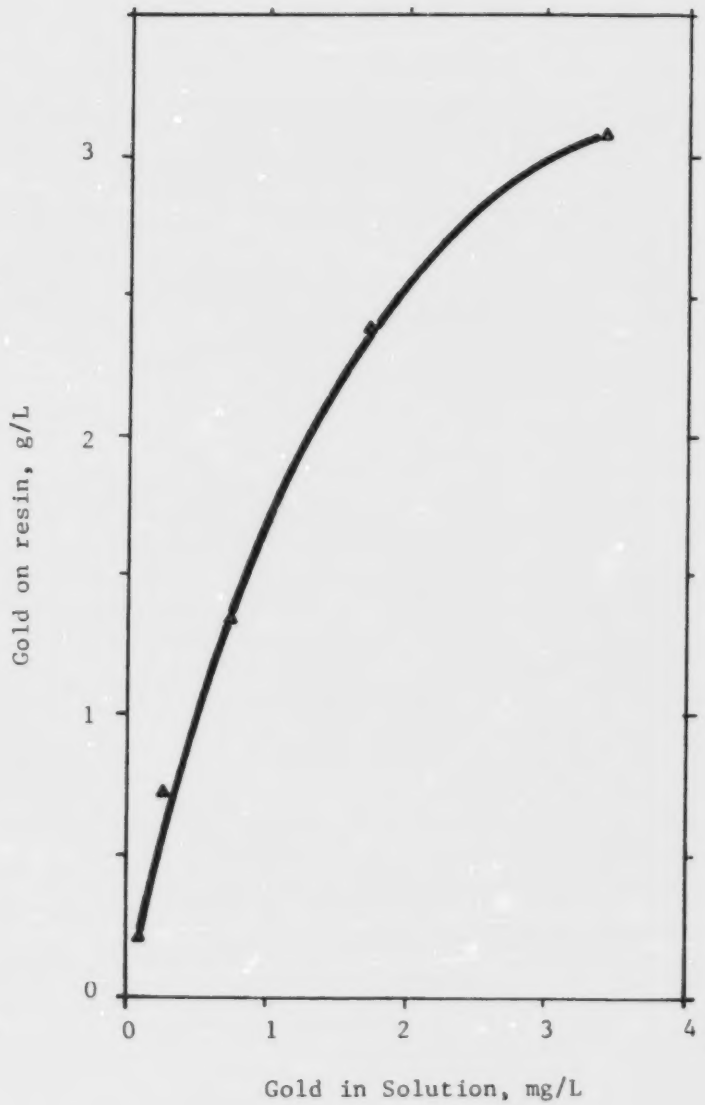

FIGURE 10: GOLD ADSORPTION ISOTHERM

6.3 Resin Losses

During the 10-day pilot program, all resin volumes added to and recovered from the RIP circuit were measured and recorded, allowing for the calculation of an overall resin volume balance.

In total, 3510 mL of resin was added to the RIP circuit, and 3322 mL of resin was recovered from the circuit, resulting in a calculated net recovery of 95% of the resin. The remaining 5% is within experimental error, considering the difficulties encountered when measuring minimal resin volumes and the number of samples measured in total.

In addition, the discharge pulp stream from Tank 5 was inspected frequently to observe the quantity of resin escaping the circuit via the interstage screens. An occassional resin bead was observed in the discharge stream during the last 3 days of operation; it is estimated that less than 1% of the resin was lost in this manner.

Further resin attrition tests were carried out during the follow-up test program; see Section 7.3 for the results.

6.4 Summary of Pilot Plant Results

During Run 1, high gold levels (1 to 2.4 mg/L) in the treated barren solution appeared to be due either to resin saturation or to insufficient resin/pulp contact time. It was suspected that the resin B and C mixture had a lower adsorption capacity than the resin (resin A) tested during the preliminary test program. This possibility was investigated during the follow-up test program (Section 7.1.2).

During Run 2, when the pulp feed rate was reduced by a factor of three, the barren gold level rapidly dropped to about 0.6 mg/L gold. However, the subsequent use of eluted resin containing residual gold precluded the attainment of the target barren level of 0.01 mg/L gold. When the addition of fresh resin was resumed, the gold barren level again decreased, reaching 0.1 mg/L gold in the Tank 5 discharge prior to shutdown.

The resin was capable of achieving lower gold barren levels. This was demonstrated by the addition of a sixth tank to the circuit containing an excess of resin. After 12 h of operation, a barren level of 0.04 mg/L gold was achieved.

Ninety-five percent of the resin added to the RIP circuit was recovered, either as resin advanced from Tank 1 or upon shutdown. The unaccounted for 5% of the resin is within the range of experimental error associated with measuring minimal resin volumes. Resin attrition was investigated independently during the follow-up program (see Section 7.3).

The second 10-day campaign was cancelled due to the unavailability of resin which could be eluted efficiently to less than 0.06 g Au/L of resin. Follow-up test work was planned by Witteck and approved by CANMET in order to confirm the tentative conclusions drawn above. The results of the follow-up test program are provided in Section 7.

7.0 FOLLOW-UP LABORATORY TESTWORK

During the Phase II pilot operation, gold loadings on the resin were much lower than anticipated, based on both the preliminary resin evaluation testwork (Section 4.1) and the Phase I benchscale program. This resulted in an excessive level of gold in the barren pulp discharged from the resin-in-pulp circuit.

Since a number of experimental conditions varied somewhat amongst the three test programs being compared (i.e. gold levels in solution, resin mesh size, pulp mesh size, percent solids, available cyanide levels, pH etc.) it was decided to compare the 1986 resin with the pilot plant resin under identical test conditions. The parameters to be investigated and compared were:

- o adsorption capacity
- o adsorption kinetics
- o elution performance
- o resin attrition

7.1 Adsorption Capacity and Kinetics

7.1.1. Variance with Resin Batch

The objective of this test was to compare the 1986 resin sample to one of the Phase II resin samples under identical conditions using the current shipment of Teck-Corona pulp.

For these tests, the resin samples were prescreened to 100% plus 32 mesh, to simulate pilot plant conditions.

The two resin samples compared were:

- o Resin A - 10 L sample received on February 13, 1987 and used during Run 2 of pilot program
- o 1986 resin sample used during the Phase I benchscale test program.

The resin samples were loaded to capacity by repeated contact with pregnant Teck-Corona filtrate. Kinetic samples were taken after 1,2,4, and 24 hours of contact. After 24 hours, the resin was recovered from the solution and was contacted with fresh pregnant solution for a further 24 hours. This was repeated until the resin had been contacted five times with fresh gold-bearing solution, 24 hours per contact. In this manner, the resin was loaded to equilibrium capacity.

Similarily, a sample of fresh resin was added to the solution recovered from the first resin/pulp contact described above. After 24 hours contact, the solution was recovered and contracted with a fresh sample of resin. This was repeated until the original gold-bearing solution had been contacted with a total of four samples of fresh resin. In this manner, "barren" effluent was produced.

The data obtained are summarized in Table 20 and Figures 11 to 13. The kinetic samples taken during the first contact (Figure 11) indicate that resin A displayed faster loading kinetics than the resin used during Phase I. For resin A, 57% of the 24 hour equilibrium loading capacity was achieved within the first 2 hours, compared to 50% for the 1986 resin.

Results obtained during the preliminary testwork (see Section 4.1) indicated that resin A, prescreened to 100% minus 32 mesh, adsorbed 76% of the 24 hour equilibrium capacity within the initial 2 hours of contact. These results confirm our original assumption that mesh size affects loading kinetics, with the finer fractions displaying faster loading kinetics.

After five contacts, the maximum loading obtained using the Teck-Corona gold-bearing solution was 7.2 g of gold per litre of resin using the 1986 resin sample and 11.2 g/L for resin A used during the pilot program.

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Table 20

RESIN COMPARISON TESTS, GOLD ADSORPTION CAPACITY*

Sample	Gold in Solution, mg/L		Gold on Resin, g/L	
	1986 Resin	Resin A	1986 Resin	Resin A
Head	5.70	5.70	-	-
Contact 1, 1h	4.49	3.96	1.21	1.74
2h	3.90	3.22	1.80	2.48
4h	3.30	2.46	2.40	3.24
24h	2.09	1.35	3.61	4.35
Fresh Solution:				
Contact 2	3.68	2.77	5.63	7.28
Contact 3	4.73	4.08	6.60	8.90
Contact 4	5.14	4.68	7.16	9.92
Contact 5	5.51	5.03	7.35	10.59
Resin Assay	-	-	7.25	11.20
Contact 6	5.40	5.48	7.65	10.81
Contact 7	5.75	5.74	7.65	10.81
Resin Assay	-	-	7.83	11.28
Fresh Resin:				
Contact 2	0.30	0.09	1.79	1.26
Contact 3	0.042	0.011	0.26	0.08
Contact 4	0.004	0.004	0.04	<0.01

Test carried out with plus 32 mesh resin and gold-bearing filtrates. Contact size, 15 litres solution, 15 mL resin.

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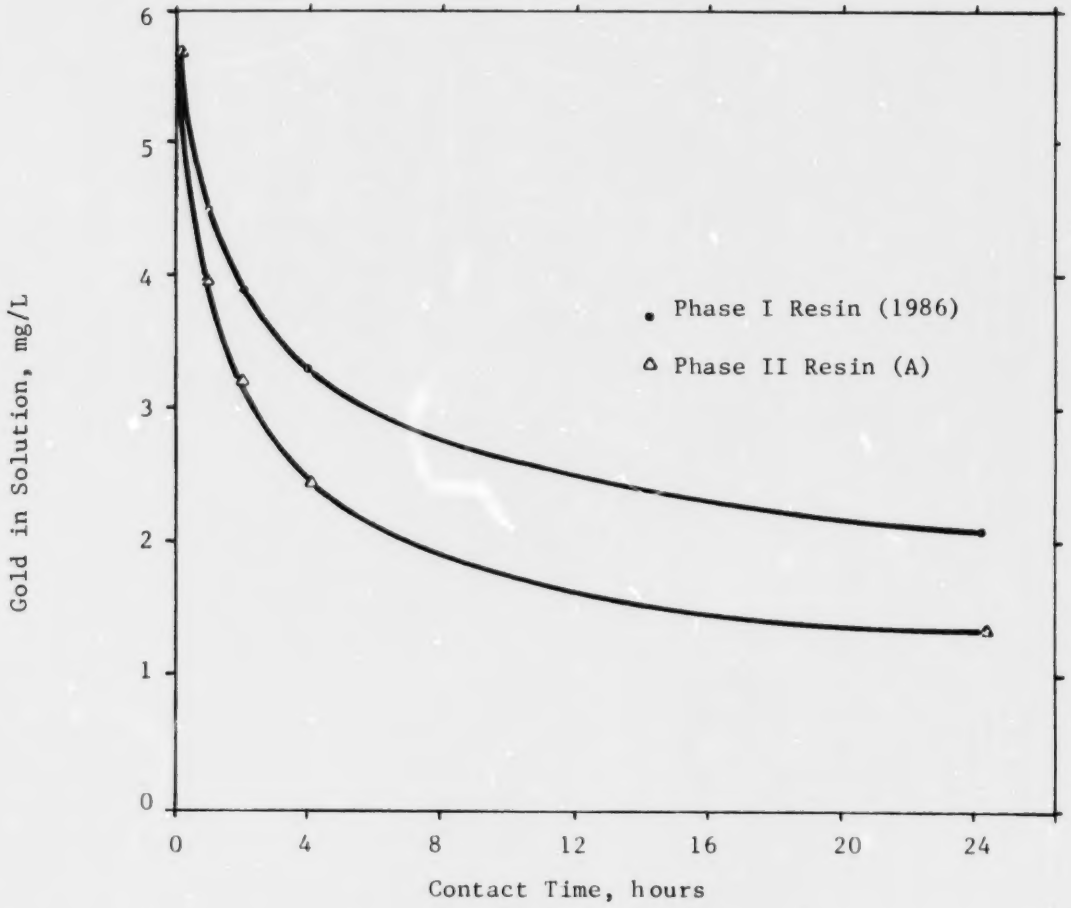

FIGURE 11: COMPARISON OF ADSORPTION KINETICS FOR PHASE I AND PHASE II RESINS

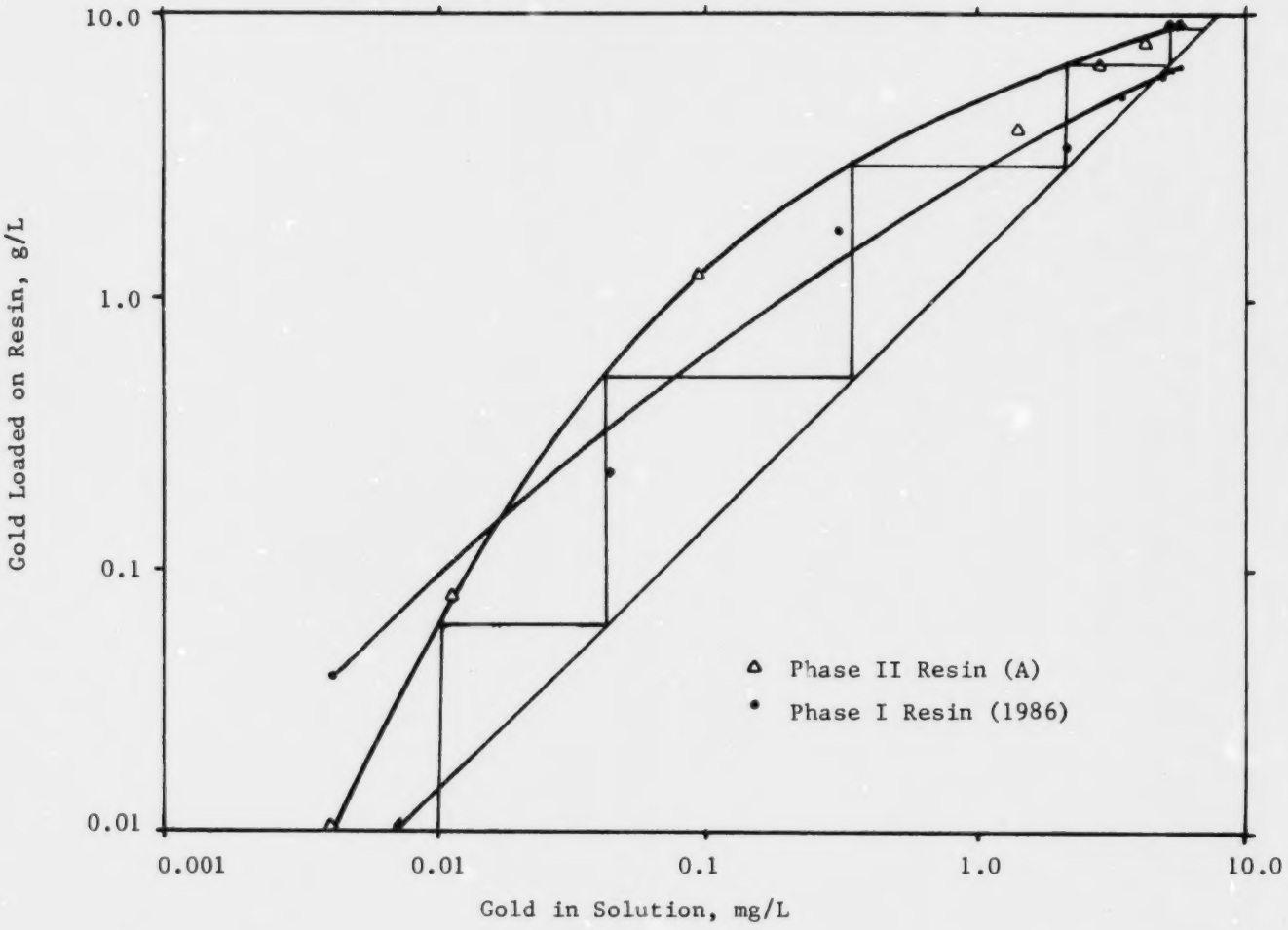

FIGURE 12: ADSORPTION ISOTHERMS FOR PHASE I AND PHASE II RESINS; SHOWING OPERATING LINE FOR RUN 1

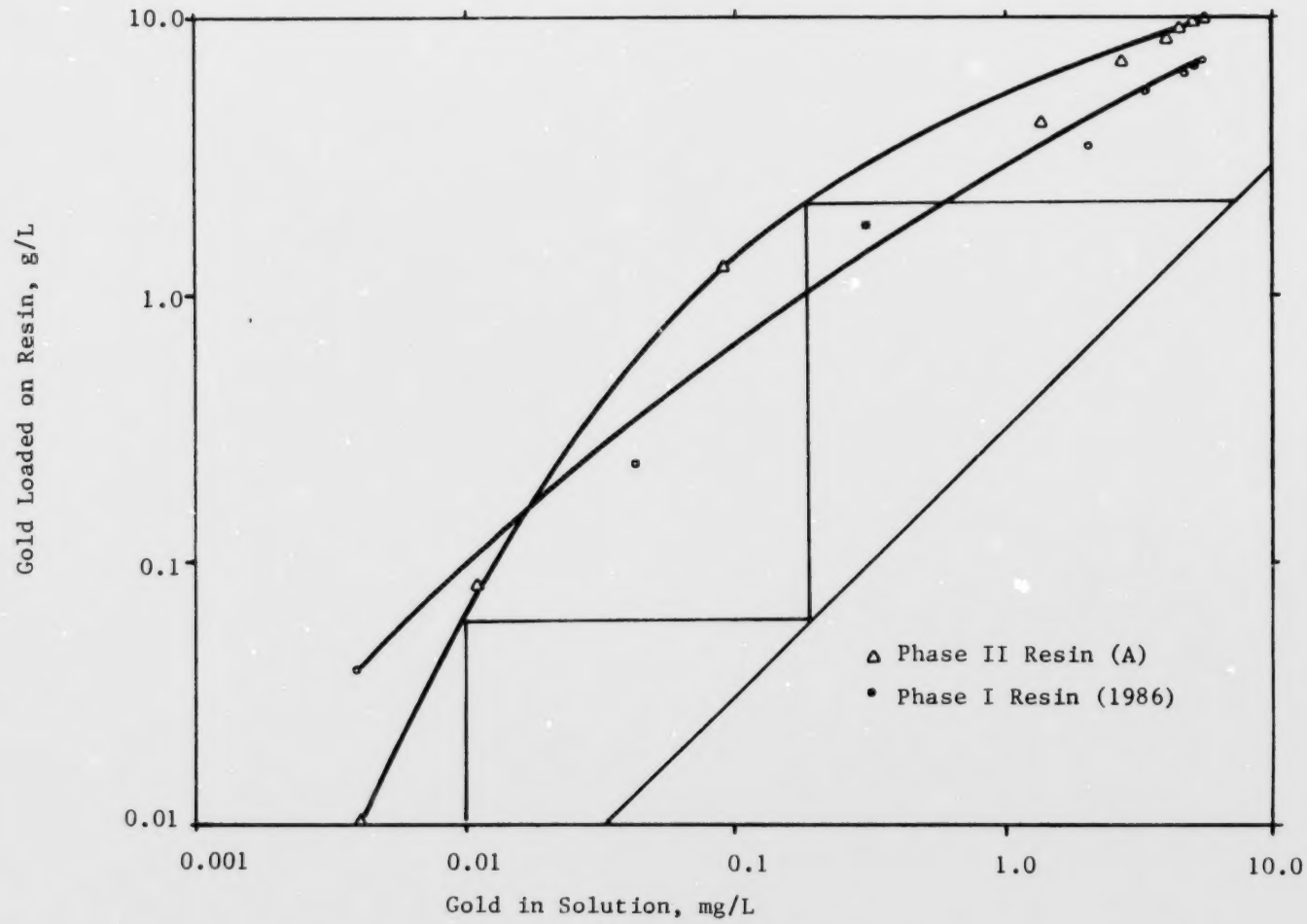

FIGURE 13: ADSORPTION ISOTHERMS FOR PHASE I AND PHASE II RESINS; SHOWING OPERATING LINE FOR RUN 2

To confirm that both resin samples were indeed loaded to full capacity, two additional contacts with fresh gold-bearing solution were performed on the resin recovered from the fifth contact. The final gold assays for the two resin samples increased slightly to 7.8 g Au/L resin and 11.3 g Au/L resin, respectively.

The results indicate that the resin A sample received for the pilot run has higher adsorption capacity for gold than the resin used during the 1986 Phase I program, under identical condition and using the same feed stock.

For both resins, the gold loading isotherms are provided in Figures 12 and 13, along with the operating line for the first (Figure 12) and second (Figure 13) run of the pilot run. Interpolation indicates that for resin A, the resin must be eluted to less than 0.06 g Au/L resin prior to recycle to the RIP circuit, if barren levels of less than 0.01 mg/L gold are desired. Similarly, for the 1986 resin, eluted resin must contain less than 0.09 g Au/L resin prior to recycle to adsorption. Higher residual gold levels would result in higher levels of gold in the barren effluent.

During Run 1, there was no residual gold on the resin since only fresh resin was used. During Run 2, high residual gold levels were presented on the "eluted" resin, due to the poor elution characteristics displayed by the resin.

Application of McCabe-Thiele diagrams to both Figures indicate that five stages would be required under Run 1 operating conditions to achieve the target barren levels; two stages would be required under Run 2 operating conditions. During both runs, an adequate number of stages (five) were provided based on the above data for resin A.

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The observed capacity of 11.3 g Au/L resin using the plus 32 mesh fraction of resin A represents a 15% increase over the capacity of 9.8 g/L observed during the preliminary testwork using the minus 32 mesh fraction. Based on mesh size alone, capacity should decrease with increasing resin bead size, not increase as observed. It is assummed that the opposite effect may be caused in some way by the absence of solids in the current testwork; the preliminary work was performed using 50% solids pulp. While clarification of the cause is outside the scope of the current program, it may be attributed to either less efficient resin/pulp contact in the agitated vessel due to poor mixing at high pulp density (1.41 kg/L), or to scaling/poisoning by some agent (e.g. silica) present in the solid phase but absent in the filtrate.

7.1.2. Capacity of Resin B & C and Variance with Mesh Size

The objective of this test was to clarify the relationship between resin capacity and mesh size noted above, and to investigate the capacity of the resin B and C mixture used during Run 1. A second series of kinetic and adsorption isotherm tests were carried out using a sample of minus 32 mesh resin B and C and plus 32 mesh resin B and C, in contact with the Teck-Corona pulp.

The results, presented in Table 21, and Figures 14 and 15 confirm that capacity increases with decreasing resin bead size. These resin samples were loaded to somewhat less than full capacity, as indicated by the final solution analyses for the fourth contact. However, judging from the shape of the loading isotherms, it seems unlikely that full capacity would reach 9 g/L for the minus 32 mesh fraction or in excess of 7.5 g/L for the plus 32 mesh fraction.

Table 21

RESIN COMPARISON TESTS, CAPACITY AND MESH SIZE*

Sample	Gold in Solution, mg/L		Gold on Resin, g/L	
	+32 mesh	-32 mesh	+32 mesh	-32 mesh
Head	6.04	6.04	-	-
Contact 1, 2h	2.67	1.97	2.36	2.85
4h	1.90	1.44	2.88	3.21
6h	1.60	1.18	3.08	3.38
8h	1.47	1.15	3.16	3.40
24h	0.94	0.74	3.49	3.65
Fresh Solution:				
Head	6.31	6.31	-	-
Contact 2	2.72	1.96	6.02	6.71
Contact 3	4.51	4.05	7.26	8.27
Contact 4	6.22	5.90	7.32	8.56

* Tests carried out using Teck-Corona pulp. Contact size: 1 mL of resin B & C, 1 L pulp (0.7 L filtrate). Loss of solution due to removal of 20 mL sample included in calculations.

Resin B and C, used during Run 1, displayed significantly lower capacity compared to the 11.3 g/L value obtained above using the plus 32 mesh resin A. Again, part of this difference may be due to the presence of pulp in the current test. However, if a comparison is made between the loading capacities of the minus 32 mesh fractions in contact with pulp, resin A (9.8 g Au/L resin) had 30% higher capacity than resin B and C (7.5 g Au/L resin) under identical conditions.

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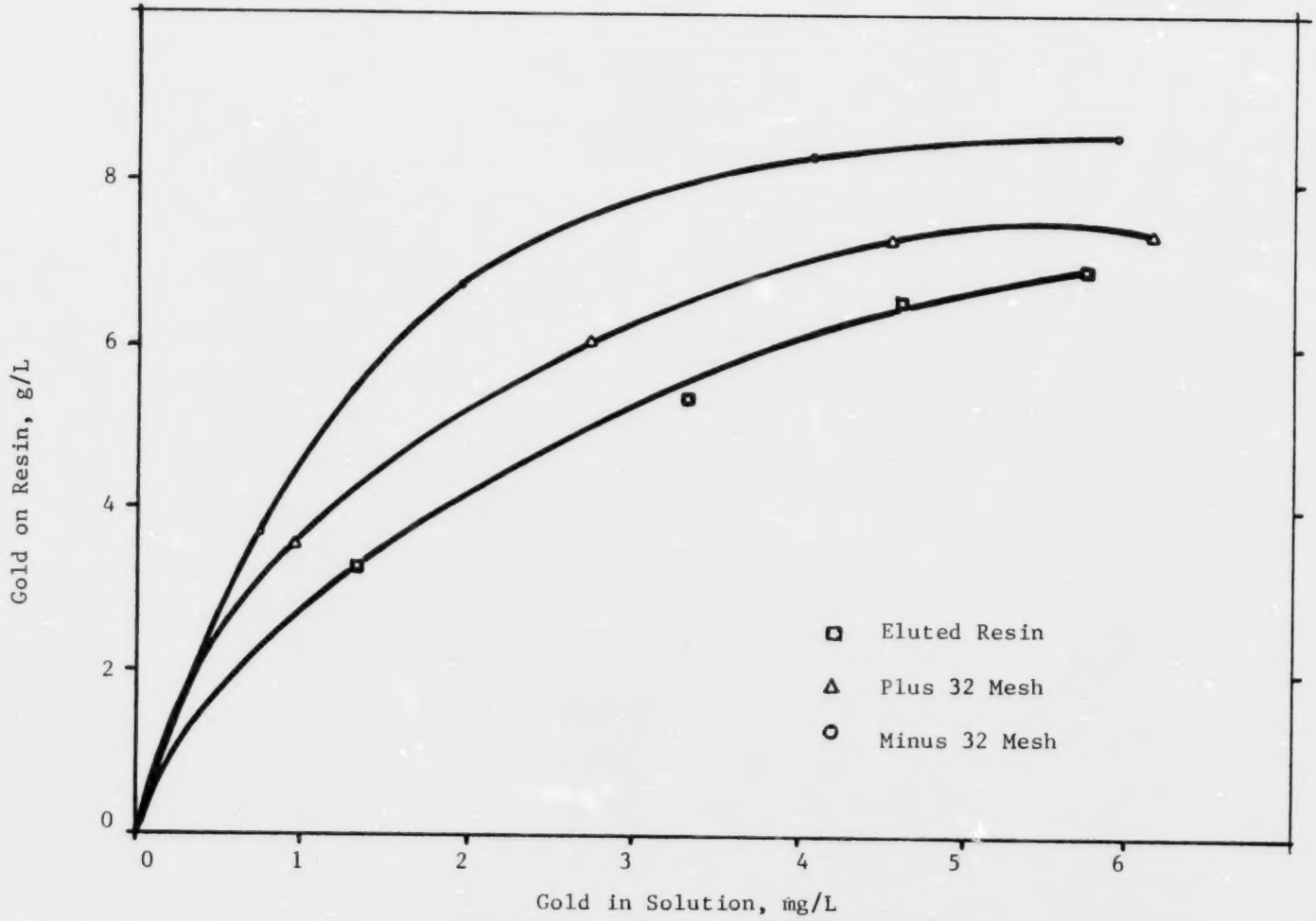

FIGURE 14: COMPARISON OF EQUILIBRIUM ADSORPTION ISOTHERMS FOR PLUS 32 AND MINUS 32 MESH, AND ELUTED RESIN A & B

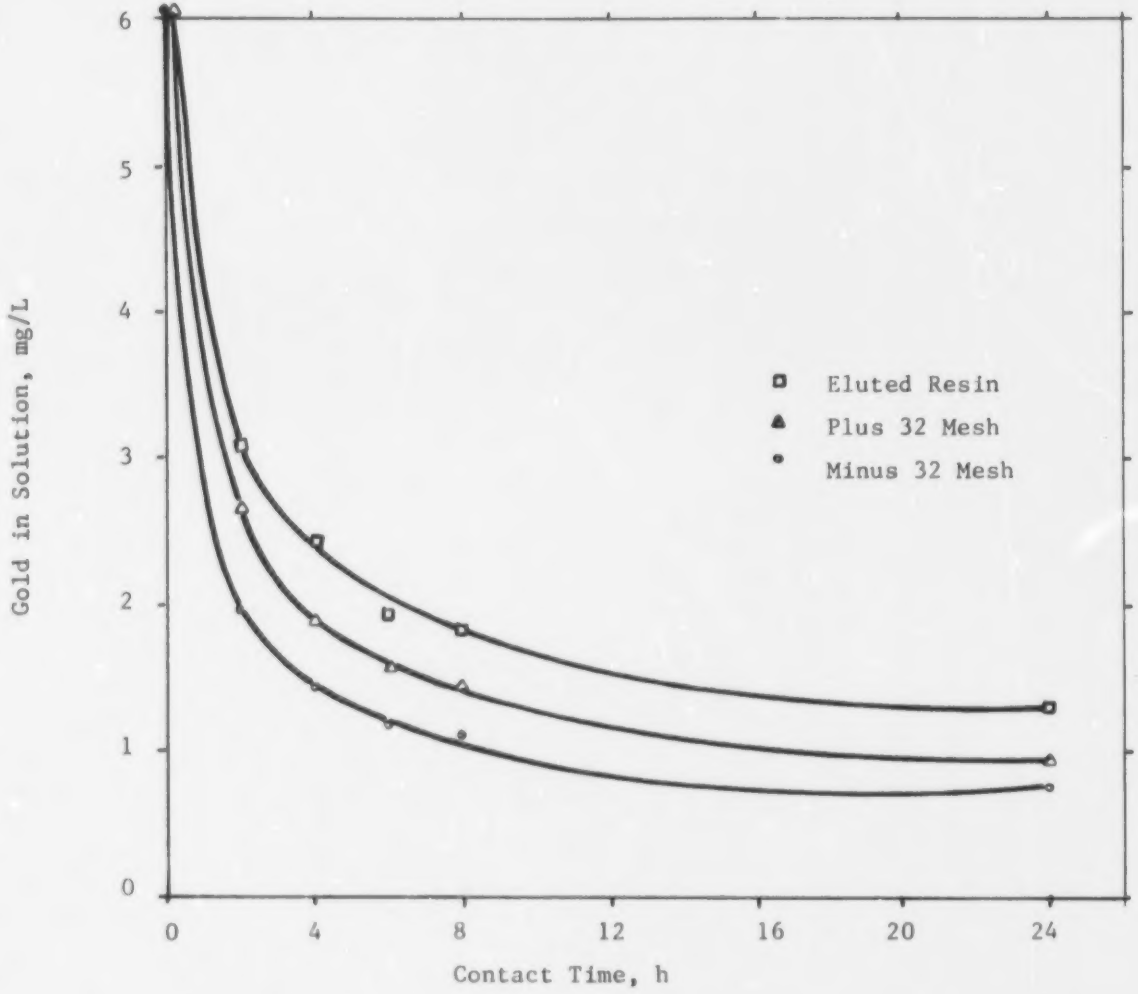

FIGURE 15: COMPARISON OF ADSORPTION KINETICS FOR PLUS AND MINUS 32 MESH, AND ELUTED RESIN B & C

The observed capacity of 7.5 g Au/L resin for the plus 32 mesh fraction of the resin B and C mixture when in contact with the Teck-Corona pulp is lower than the design loading criteria of 10 g Au/L resin. It is concluded that indeed insufficient resin was present in the circuit during Run 1 to adsorb all of the gold present.

The kinetic data taken over the first 24 hours indicate that the minus 32 mesh fraction displayed faster adsorption kinetics than the coarse fraction, as expected. For the fines, 78% of the 24 hour equilibrium capacity was attained within the first 2 hours of contact; compared to only 68% for the coarse fraction.

Table 22 summarizes and compares all of the kinetic data available to date.

Table 22

PERCENT OF EQUILIBRIUM CAPACITY ATTAINED WITHIN INITIAL 2 HOURS

1986 Resin	Resin A	Resin B
68% * (+50 mesh, solution)	76% ** (-32 mesh, pulp)	78% (-32 mesh, pulp)
50% (+32 mesh, solution)	57% +32 mesh, solution)	68% (+32 mesh, pulp)

* Phase 1 Testwork
** Preliminary Testwork (Section 4.1)

It is concluded that the three resin samples displayed different kinetics, but in all cases the fines fraction adsorbed gold faster than coarse fraction.

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For the 1986 resin, the resin was prescreened to 100% plus 50 mesh during the Phase 1 benchscale testwork. The difference observed, 68% of equilibrium capacity during the initial 2 hours for the plus 50 mesh resin compared to 50% for the plus 32 mesh fraction is as large as the difference observed between the plus and minus 32 mesh fractions of the other two resins, A and B. It is assummed that some of this variation is due to the differences in the feed solutions (i.e. gold and zinc levels, pH, available cyanide and lime levels etc) from one year to the next.

7.1.3 Adsorption Capacity and Kinetics of Eluted Resin

In order to investigate the capacity of the plus 32 mesh eluted, recycled resin, a sample recovered from the elution circuit was submitted to the same test as that described in Section 7.1.2 for the plus and minus 32 mesh samples of resin B and C. The eluted resin was contacted in four stages with Teck-Corona pulp, 24 hours per contact. The results are presented in Table 23 and compared to the fresh resin B and C mixture in Figures 14 and 15.

As anticipated, the eluted resin had lower capacity (less than 7 g Au/L resin) and slower kinetics (64% of the 24 hour equilibrium capacity was attained within the first two hours) than either the plus 32 mesh or the minus 32 mesh fresh resin B and C samples.

Table 23

ADSORPTION CAPACITY OF ELUTED RESIN*

Sample	Gold in Solution, mg/L	Gold on Resin, g/L
Head	6.04	-
Contact 1,2h	3.09	2.06
4h	2.43	2.51
6h	1.92	2.85
8h	1.83	2.91
24h	1.31	3.23
Fresh Solution		
Head	6.31	-
Contact 2	3.32	5.33
Contact 3	4.60	6.51
Contact 4	5.76	6.90

* Test carried out using Teck-Corona pulp; Contact size: 1 mL resin in 1 L of pulp. Loss of solution due to removal of 20 mL samples included in calculations.

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7.2 Elution Characteristics

During the preliminary test program (Section 4.1) and the pilot plant operation (Section 6.1), it was noted that the resin received for the Phase II program demonstrated poorer elution performance than that obtained during 1986 for the Phase 1 program. This resulted in high levels of residual gold on the "eluted" resin. Consequently, once the eluted resin was recycled to the adsorption RIP circuit during Run 2, the objective of less than 0.01 mg/L gold in the barren pulp filtrate was impossible to achieve.

To confirm this finding, the two resin samples which were loaded to capacity under identical conditions (see 7.1.1: Resin A, 11.2 g/L and the 1986 resin, 7.25 g/L after five contacts) were eluted under identical conditions using the 1% NaCN, 1% NaOH eluant, maintained at 90 to 93°C. The resin samples were eluted one bed volume at a time, one hour contact per bed volume, sixteen contacts in total. Between contacts, the resin was recovered from the hot eluate, rinsed with one bed volume of 1% NaOH at 93°C. The eluate and sodium hydroxide rinse solutions were combined and asayed for total gold content.

The data obtained are tabulated in Table 24 and are plotted in Figure 16. The gold elution performance of the two resins were considerably different. Based on solution analyses, 95% of the loaded gold was eluted from the 1986 resin within 16 volumes, compared to only 77% recovery from the phase II resin A. The calculated residual gold levels on the resins were 0.33 g/L and 2.54 g/L, respectively. To confirm these values, the eluted resin samples were assayed for gold. The 1986 resin assayed 0.13 g/L Au and the Phase II resin A sample assayed 1.21 g/L Au. These values confirm the relative elution performances.

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Table 24

RESIN ELUTION COMPARISON TESTS: 1986 RESIN AND RESIN A

Gold Adsorbed: Resin A, 11.2 g/L
1986 Resin, 7.25 g/L

	Cumulative Percent Gold Eluted	
Bed Volume	Resin A	1986 Resin
1	28.7	45.0
2	43.9	64.4
3	49.9	72.1
4	54.5	77.9
5	58.5	82.5
6	61.7	85.4
7	64.4	87.4
8	66.4	89.0
9	68.4	90.3
10	69.9	91.4
11	71.3	92.1
12	72.6	92.8
13	74.1	93.8
14	75.4	94.5
15	76.3	95.0
16	77.3	95.4
Residual Gold, g/L	1.21	0.13
Total Eluted (based on resin assays)	89.2	98.2

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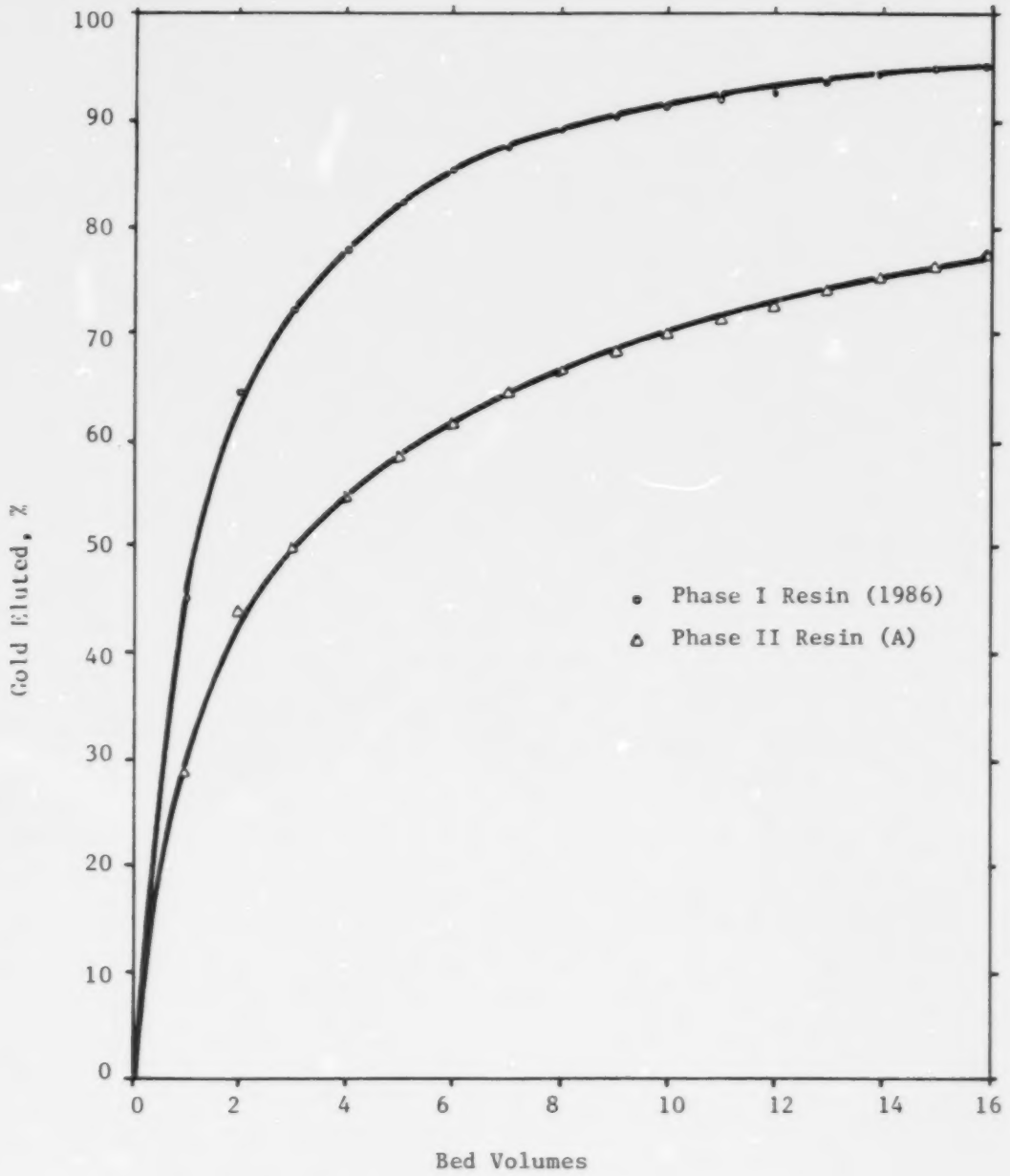

FIGURE 16: COMPARISON OF ELUTION PERFORMANCE FOR PHASE I AND PHASE II RESINS

The residual gold loadings based on resin analyses are assumed to be more accurate than those based on solution analyses since the latter value represents a summation of sixteen separate assays, each of which may have an associated error of up to 5%.

While the residual gold level on the 1986 resin, 0.13 g/L, was close to the 0.09 g/L level required prior to reuse, resin A contained far in excess of its required residual gold level of 0.06 g/L.

For the above test, the two resin samples were loaded to capacity. This test was repeated using all four resin types received, loaded to similar levels, approximately 10 g gold per litre of resin.

The four resin samples were:

1986	-	Resin received in 1986 for Phase 1 test program.
A	-	10 L batch received February 13, 1987.
B	-	1 L batch received March 6, 1987 and 1 L batch received March 18, 1987
C	-	2 L batch received March 18, 1987.

Unfortunately, insufficient quantities remained of the plus 32 mesh fraction for all four resin types. Therefore, the minus 32 mesh fractions were used. It is assumed that with the exception of elution kinetics, the same relative elution performances would be observed with the minus 32 mesh fraction as with the plus 32 mesh fraction.

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The resins were loaded to approximately 10 g gold per litre of resin using a synthetic aurocyanide solution (0.85 g/L gold as potassium aurocyanide, 0.4 g/L sodium cyanide, pH 10.5 lime water). The resin was contacted with an aliquot of the aurocyanide solution for one hour, separated from the barrens solution and contacted with a second aliquot of the synthetic gold solution for a further one hour. This was repeated for a total of six contacts. The loaded resin was separated and washed with water. The wash water and the six barren aliquots were combined and assayed for gold. The loaded resin was assayed for gold. The results are provided in Table 12.

It should be noted that the objective was to load all four resin samples to the same level (10 g Au/L resin), not to load to maximum equilibrium capacity. The 11.1 g/L loading for resin A is only 10% higher than the 9.8 g/L level obtained using the minus 32 mesh fraction during the Preliminary Testwork (Section 4.1). However, the 11.0 loading for the 1986 resin is significantly higher than the 7.8 g/L observed using the plus 32 mesh fraction during the follow-up testwork. Similarly for resin B, the 11.3 g/L loading is signficantly higher than the 8.6 g/L observed using the minus 32 mesh fraction. The higher capacities achieved are attributed to the use of synthetic gold solution. i.e. an absence of zinc, pulp and other contaminants.

The loaded resins were eluted using the 1% sodium cyanide, 1% sodium hydroxide eluant at 90 to 93^{o}C. The resin was agitated in one bed volume of eluant for one hour, separated from the eluate, rinsed with 1% sodium hydroxide at approximately 93^{o}C, and washed with water. The eluate, rinse and wash water were combined and assayed for gold. The eluted resin was assayed for gold. The results are presented in Table 25.

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Table 25

RESULTS OF THE RESIN ELUTION COMPARISON TEST

	RESIN SAMPLE			
Cycle	1986	A	B	C
Adsorption:				
Au loaded on resin, g/L	11.0	11.1	11.3	10.8
Elution:				
Au eluted, %	56%	17%	62%	38%

Resin A displayed poor elution characteristics, only 17% of the adsorbed gold was recovered in the first bed volume of eluant, compared to 56% for the 1986 resin sample. Resin B showed similar elution behaviour to the 1986 resin sample. However, Resin C displayed characteristics between the two former samples, as originally predicted by Dow Chemical representatives.

The inability to produce acceptable gold barren levels (0.01 mg/L Au) observed during the second run of the Phase II pilot plant campaign can be attributed in part to the poor elution performance of the resin used (resin B & C).

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7.3 Attrition: Resin versus Carbon

A test program to compare attrition losses between coconut shell carbon and ion exchange resin was carried out. The carbon used during the program was obtained from the CIP circuit of Teck-Corona Operating Corporation. The carbon was well aged, having been through several stripping and regenerating cycles. The resin used during testing was the Dow XU-40114.00 resin used during the resin-in-pulp pilot plant campaign.

The attrition tests were carried out in two of the contactors in the five-stage resin-in-pulp circuit. Each 70 L tank was equipped with one dual axial-flow impeller operating at 600 rpm. Each tank contained 54 L of the Teck-Corona pulp (50% solids; P.D. 1.41 kg/L).

In order to determine the relative size distribution of the carbon and resin prior to the attrition test, each material was subjected to a preliminary screen analysis. The results are presented in Tables 26 and 27, respectively.

The carbon was added to the pulp to achieve a concentration of 15 g of carbon per litre of pulp, typical of commercial carbon-in-pulp circuits. Resin was added to achieve a comparable level of 15 mL/L of pulp.

The resin/pulp and carbon/pulp mixture were agitated for at least 600 hours. Make-up water was added as required to compensate for evaporation losses and maintain a constant pulp density.

It was expected that the carbon loss due to attrition might be higher during the initial stages than the average overall loss. Therefore, a carbon inventory was completed at periodic intervals until a uniform rate of attrition was established. This was carried out by periodically screening the carbon/pulp mixture through a 32 mesh screen, and drying and weighing the carbon recovered in the oversize fraction. The carbon was then returned to the pulp and the attrition test was continued. This provided an attrition versus time profile for the carbon.

Resin attrition was expected to be uniform with time and therefore no intermediate resin inventories were carried out.

At the end of the 600 hour test, the carbon and resin were recovered from the slurry by screening through 32 mesh and 48 mesh screens, respectively . A final inventory was performed and the amount of carbon/resin lost due to attrition was calculated. Screen analyses were performed on the recovered carbon and resin for comparison with the initial size distribution data. The results are discussed below.

Carbon:

The carbon recovery and size distribution data are presented in Table 26. The carbon-slurry attrition test ran for 615 hours. The amount of dry carbon recovered in the plus 32 mesh fraction was 674 g, corresponding to an overall loss of carbon due to attrition of 122 g or 15%. The size distribution altered slightly from 93% plus 14 mesh before the test to 90% plus 14 mesh after the test.

The profile of carbon losses over the total test period is presented in Figure 17. This profile indicates that 58% of the total test loss occurred within the initial 66 hours. This implies that two types of attrition may be occurring. During the initial stages, the rapid carbon loss is most likely due to abrasion of the rougher particle edges. Although the carbon was used carbon from the Teck-Corona CIP circuit, the abrasion which the carbon would be subjected to in a full-scale operation was apparently less intense than that experienced by the carbon under pilot plant conditions. This was followed by a period of slower constant attrition.

Table 26

CARBON SCREEN SIZE DISTRIBUTIONS

Mesh Size	Before Attrition Test Weight g	%	Cumulative % Retained	After Attrition Test Weight g	%	Cumulative % Retained
8	1.4	0.2	0.2	0	0.0	0.0
10	179.6	22.6	22.7	96.0	14.2	14.2
14	560.0	70.4	93.1	509.0	75.5	89.7
20	53.5	6.7	99.8	66.0	9.8	99.5
28	1.0	0.1	99.9	2.8	0.4	99.9
32	0.5	0.1	100.0	0.5	0.1	100.0
-32	0	-	-			
Total	796.0		Total	674.3		

Percent Recovered: 85%

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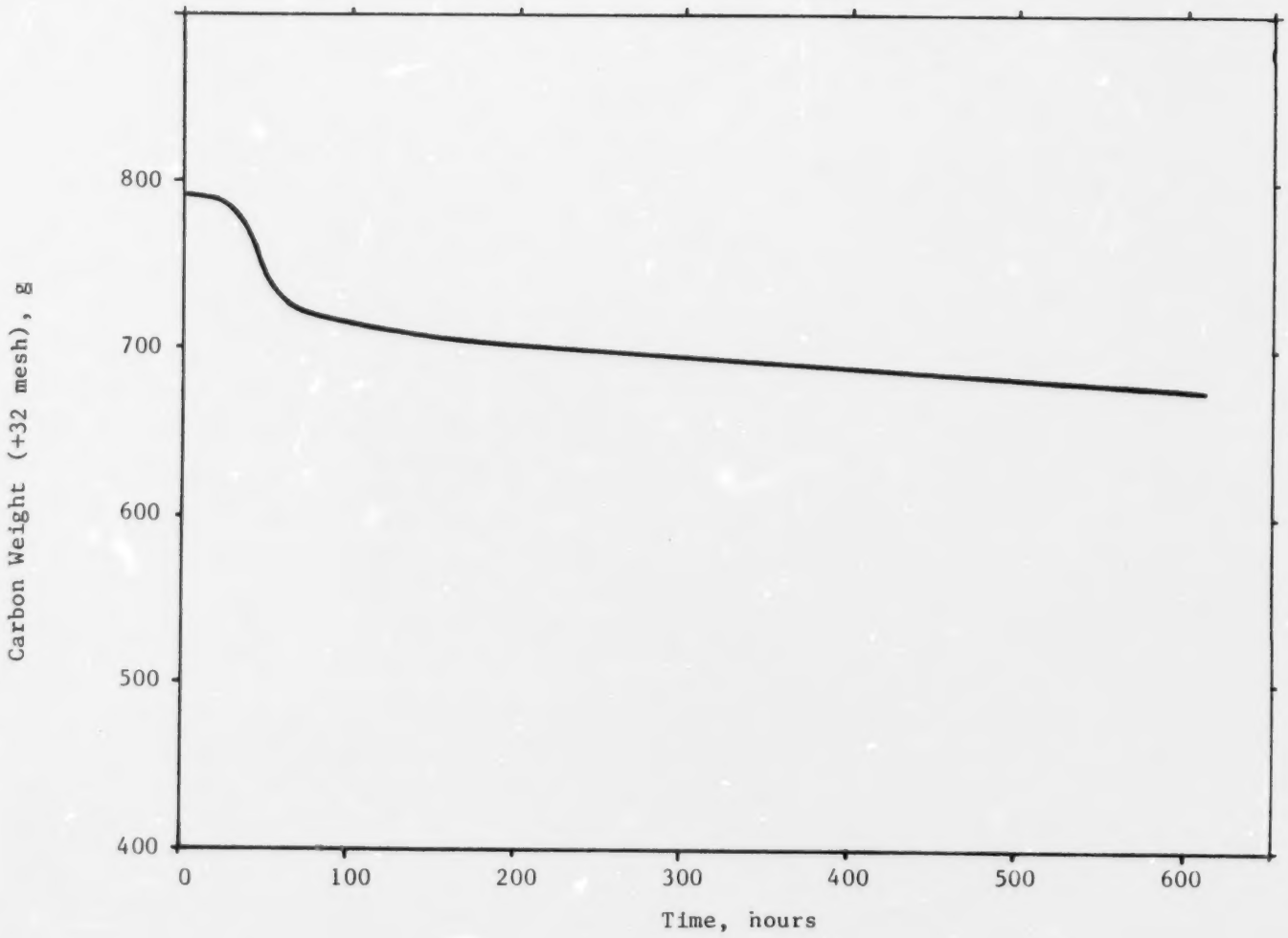

FIGURE 17: CARBON ATTRITION PROFILE

Resin:

The resin recovery and size distribution data are provided in Table 27. The resin-slurry attrition tests lasted for 624 hours. The amount of resin recovered in the plus 48 mesh fraction was 830 mL, corresponding to an overall gain in resin volume of 15 mL or 1.8%. During recovery by screening, it was noted that a small amount of extraneous solids were recovered with the resin. The observed volume gain is attributed to solids contamination from the pulp. The relative size distribution was not altered by the attrition test.

Table 27

RESIN SCREEN SIZE DISTRIBUTIONS

Mesh Size	Before Attrition Test Volume mL	Volume %	Cumulative % Retained	After Attrition Test Volume mL	Volume %	Cumulative % Retained
20	15.0	1.8	1.8	15.0	1.8	1.8
28	690.0	84.7	86.5	695.0	83.7	85.5
32	110.0	13.5	100.0	120.0	14.5	100.0
48	0	-	-	0	-	
-48	0	-	-			
Total	815.0			830.0		

Percent Recovered: 102%

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To assess the loss of carbon and resin due to handling alone, two inventory checks were conducted for each of the materials. This was done by contacting the carbon and resin with pulp in their respective tanks and agitating for one hour to ensure homogeneity. Each tank was then screened to recover the carbon or resin and an inventory conducted to determine the loss of material due to manipulation. In both cases, 100% of the carbon/resin was recovered, indicating that the 15% loss of carbon was indeed due to attrition under pilot plant conditions.

As these tests were carried out batchwise, no conclusions can be drawn with respect to the predicted rate of resin attrition per ton of ore treated. However, it is concluded that the resin would be less prone to attrition than carbon under identical conditions.

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7.4 Summary of Results of Follow-Up Test Program

The following conclusions were drawn from the follow-up adsorption, elution and resin attrition testwork.

- Capacity increases with decreasing resin bead size.
- Adsorption kinetics are faster with finer mesh size resin.
- Resin A had higher gold loading capacity than the resin received for the 1986 benchscale program.
- Resin A adsorbed gold faster than the resin received for the 1986 benchscale program.
- A sufficient number of contactor stages were provided for both Run 1 and 2, based on the observed maximum equilibrium loading capacity of Resin A.
- Resin B & C, used during Run 1, displayed a lower maximum equilibrium adsorption capacity than Resin A under identical conditions (-32 mesh resin in contact with 50% solids Teck-Corona pulp).
- Eluted resin B & C had the lowest maximum equilibrium capacity of all resin samples tested to date.

- High gold levels in the barrens during Run 1 of the pilot campaign was due to insufficient resin present in the RIP circuit. This was due to a combination of factors:

  - the lower adsorption capacity displayed by resin B and C.
  - insufficient contact time provided per contact stage
  - the difficulties encountered in scaling-up a three-phase system, i.e. solids, liquid and resin beads.

- The 1986 resin and resin A must be eluted to less than 0.09 and 0.06 g of gold per litre of resin, respectively, in order to obtain the 0.01 mg/L gold target level in the treated barren pulp when reusing the eluted resin. The 1986 resin can be eluted efficiently to the 0.1 g/L residual gold range. However, resin A contained in excess of 1 g/L residual gold after the same procedure.

- Resin B displayed similar elution characteristics to the 1986 resin sample. Resin C displayed elution characteristic mid-way between those of Resin A and the 1986 resin.

- High residual gold levels on the "eluted" resin contributed to the high gold levels in the barrens during Run 2.

- The Dow experimental resin, XU-40114.00 displayed zero attrition loss in an agitated pulp circuit. Used carbon, received from Teck-Corona's CIP circuit, displayed a 15% attrition loss under identical conditions. No conclusions can be drawn on the influence of high temperature elution on the rate of resin attrition.

8.0 CONCLUSIONS

The following conclusions were drawn on the basis of the results of the pilot program and the follow-up laboratory program.

1. Anomalies amongst the various resin batches received made the design of the pilot plant operation difficult. These anomalies included:

   - o The adsorption capacity of most of the resin used during the pilot program was lower than the resins tested during the Phase I program and the Phase II preliminary resin evaluation testwork.

   - o The resin could not be eluted to acceptable residual gold levels within a reasonable number (e.g. 10 to 15) of eluant bed volumes.

   - o The adsorption capacity of the eluted resin was lower than that of the fresh resin due to the residual gold contained.

   - o The rate of gold adsorption displayed by the pilot plant resin was comparable to that used during Phase I. However, the eluted resin displayed slower adsorption kinetics upon recycle.

2. Planning and budget constraints did not allow for adequate identification of the variation in the adsorption/elution characteristics of the multiple resin batches produced. The magnitude of the variations observed was not anticipated. In retrospect, more preliminary testwork should have been undertaken, including:

- standard resin evaluation tests using synthetic solutions

- batch-type tests carried out in the pilot plant contactors for the evaluation of process scale-up.

The cost for these additional tests would have greatly expanded the program budget.

3. Process scale-up of the RIP process is complex. The following key parameters affect the rate and quantity of gold adsorbed by the resin:

   - resin to pulp flow ratio
   - resin inventory per stage
   - retention time per stage
   - efficiency of pilot plant contactors, i.e. intensity of the agitation and relative densities of the three phases (solids, liquid, resin beads)

4. During the first part of the pilot campaign, acceptable barren levels could not be achieved because insufficient resin was provided to adsorb all of the gold present.

5. The second part of the pilot campaign theoretically was capable of demonstrating the production of acceptable gold barrens. However, acceptable gold barren levels were not achieved due to:

   - residual gold on the eluted resin
   - non-steady state conditions following the first part of the pilot program
   - possibility that the actual pilot plant contactors were less efficient than a theoretical stage.

6. As mentioned in Point 1, the bulk of the resin received for the pilot program could not be eluted efficiently, presumably due to inconsistencies at the resin synthesis stage. Therefore, no additional information on elution performance was sought or obtained.

7. Long-term resin poisoning, scaling and attrition performance could not be evaluated since the resin could not be recycled through multiple adsorption/elution cycles. However, independent testwork indicated that the resin undergoes zero attrition loss under agitated pulp conditions which resulted in a 15% carbon attrition loss.

8. No problems were encountered handling the plus 32 mesh resin in the RIP circuit which incorporated 48 mesh interstage screens for resin/pulp separation and 65 mesh screens for resin recovery. If anything, the resin and screen sizes were finer than those which would be utilized in a full-scale commercial operation.

9. Any future piloting of the resin-in-pulp process must be carried out under conditions which are more typical of full-scale carbon-in-pulp operations, i.e. 15 to 30 mL of resin per litre of pulp. Due to the larger resin inventories, a much longer period of time will be required to reach steady state operations. The program, which could require 6 months to complete, might best be conducted on-site at a Canadian gold mill. The resin to be tested must be manufactured in a single large batch or production run.

10. The maximum adsorption capacity of the resin indicated by the test runs was 5 g Au/L resin for 2 hours contact per stage. A pilot plant based on this capacity would require 9 to 13 stages (see Appendix C, Section 3.0). Therefore, process viability under these conditions must be investigated in comparison to carbon-in-pulp technology.

9.0 RECOMMENDATIONS

1. Although not all of the program objectives were achieved, the RIP process fundamentals and advantages are still valid. Therefore, continued development of the RIP process is recommended.

2. It is now apparent that a pilot demonstration of this process will be a much more costly endeavour (i.e. 6 months on-site demonstration). Therefore, a preliminary engineering feasibility study is recommended prior to further pilot work. This study would evaluate the economic incentives for resin-in-pulp compared to the more conventional carbon-in-pulp process. While not all of the design information required for a full feasibility study was obtained during this initial piloting program, acceptable estimates can be generated using the data accumulated to date, comparative resin and carbon benchscale performances, and an available carbon-in-pulp mathematical model, (Ref.1).

3. If this engineering feasibility study clearly showed sufficient economic incentive, Witteck would recommend that development proceed in two phases.

   Phase A - A resin evaluation program.
   This will be carried out on a large production batch of the DOW experimental XU-40114.00 resin. Testing should include adsorption capacity, adsorption kinetics and elution efficiency. This should be done batchwise on a benchscale basis using both synthetic gold solution and authentic gold-bearing pulp. The pulp testing should then be repeated batchwise in the actual pilot plant contactors to ensure consistency of performance scale-up.

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Phase B - The pilot plant program.

It is recommended that testing be conducted at a plant site using a process bleed stream. This should be carried out over an extended period of time to allow for multiple adsorption/elution cycles to be completed. Using a higher resin inventory (i.e. 15 to 30 mL of resin per litre of pulp) to simulate full-scale operating conditions, the time required to reach steady-state operation would be much longer than that required in the current program.

If the same pilot plant circuit were utilized (i.e. five stages, 54 L/stage, 2 hours retention time per stage) and a feed concentration of 6.5 mg/L gold in solution were assumed, then a resin flow rate of 24 mL/hour would be required to attain resin loadings of 5 g Au/L resin. Under these conditions, 21 days would be required to reach steady-state operation with a resin inventory of 15 mL/L pulp.

If a minimum number of four complete resin cycles were completed (i.e. one using fresh resin and three using eluted recycled resin) then the program would require 3 to 4 months, including a start-up/shakedown period. Operation at the higher resin inventory (i.e. 30 mL of resin per litre of pulp) would require twice the time. Therefore, a program budget based on 4 to 8 months operation is recommended.

Ref.(1) Hodouin, D.; Carrier, C.; Barbery, G.; Courchesne, M. Evaluation of the Performance of a CIP Gold Recovery Process. Paper presented at the Professional Development Seminar, April 30 to May 2, 1987, McGill University, Montreal, Canada.

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APPENDIX A

Program Plan for Pilot Plant Demonstration

APPENDIX A

PROGRAM PLAN FOR PILOT PLANT DEMONSTRATION

A.1.0 PROGRAM OBJECTIVES

To operate a 20 day pilot plant demonstration to:

- Confirm that the benchscale flowsheet developed during Phase I is operative on a pilot scale (0.5 tonne per day).
- Confirm the loading capacity and selectivity of the resin for gold.
- Confirm that acceptable barren solution levels can be obtained.
- Confirm the elution process for gold recovery.
- Evaluation of resin poisoning, scaling and attrition by recycling resin many times.
- Monitor resin handling procedures.

A.2.0 OPERATING PHILOSOPHY

During the 20 day campaign, the primary goal will be the attainment of low gold barrens (0.01 mg Au/L) and high resin loadings (10 g Au/L resin). Operating parameters will be varied accordingly.

Once the above targets are achieved, additional parameters may be varied (e.g. decreased retention time per stage).

A.3.0 DESIGN CRITERIA

Circuit is designed to treat 0.5 tonnes/day.
Slurry Characteristics (predicted)

Pulp Density = 1.41 kg/L
% Solids = 49.5

Based on cumulative data to date, the pilot plant operating parameters will be:

Number of Stages of RIP: 5
Volume per stage to overflow: 54 L
Retention time per stage: 2 h
Slurry Feed Rate: 27 L/h (450 mL/min); 38 kg/h
Solution Feed Rate: 19.1 L/h
Solids Feed Rate: 18.75 kg/h (=0.45 tonnes/day)
Gold Concentration in Solution (predicted): 6.5 mg/L
Gold Flow: 6.5 mg/L x 19.1 L/h = 124 mg Au/h
Resin Loadings: 10 to 18 mg Au/g resin (observed during Phase I for feed pulp containing 3.5 and 6.4 mg/L Au, respectively)
Resin Flow: 12.4 g/h -- 10 mg Au/g resin (assume moderate gold loading)

$$\text{Flow Ratio: } \frac{\text{Resin}}{\text{Slurry}} = \frac{12.4 \text{ g/h}}{27 \text{ L/h}} = 0.46 \text{ g/L}$$

Resin Inventory per Stage: 75 g (3 x resin flow per retention time, see Appendix B for explanation)
Resin Concentration in Pulp: 75 g/54 L = 1.39 g resin/L pulp

Resin Advancement: 12.4 g resin/h or 6.2 g resin/30 min; therefore must move 4.5 L pulp every 30 minutes

Resin Cycle Time: $\frac{75 \text{ g resin/stage}}{12.4 \text{ g resin/hour}}$ = 6.0 hours/stage x 5 stages = 30 h

Three Cycles: 90 h = 3.8 days

Pulp Cycle Time: $\frac{54 \text{ L/stage}}{27 \text{ L/hr}}$ = 2 h/stage x 5 stages = 10 hours

Three Cycles: 30 h for pulp

Available Cyanide: at least 0.2 g CN/L solution through RIP circuit

Lime Addition: to maintain pH between 9.5 and 10.0 through RIP circut

A.4.0 MATERIAL REQUIREMENTS

A.4.1 Gold-Bearing Pulp

Slurry Feed Rate = 27 L pulp/h

Require: 27 L/h x 24 h/day x 21 days = 13608 L

Drums: 91 drums (150 L each if 3/4 full)

Order: 110 drums (20% contingency)

Pulp Stabilization:*

pH: 11.5 to 12.0

[CN] avail: 0.5 g/L

* Note: Although recommended, pulp was not stabilized prior to shipment.

A.4.2 Resin

Starting Inventory: 75 g/stage x 5 stages = 375 g

Resin Feed Rate: 12.4 g/h x 24 h/day x 21 days = 6250 g

6625 g**

Ordered: 10 L (resin density 1 g/mL)

Up to 30% of the received resin may be rejected when resin is prescreened to 100% plus 32 mesh.

**Resin will be eluted and re-used. Therefore, less than 6.6 kg of fresh resin will be required.

A.5.0 PILOT PLANT CIRCUIT

A.5.1 Circuit Description (See diagram, Figure 3)

- Repulp Tank
  - repulp in 45 gal drums received
  - repulp 5 drums per day (feed for 24 hr)
  - need 2 baffles plus one agitator equipped with two 4 1/2" diameter axial-flow impeller
- Sweco Screen
  - one vibrating Sweco screen, 65 mesh.
  - pulp will flow from repulp tank to Sweco screen by siphon.
- Transfer Pump
  - for transferring 50% solids slurry from Sweco screen underflow to Conditioning Tank.
- Conditioning Tank
  - one 1300 L tank
  - 4 baffles
  - one 18" impeller
  - pulp will flow from Conditioning Tank to Feed Tank by gravity
  - pH meter
  - CN titration apparatus
- Feed Tank
  - one 45 gal drum
  - 2 baffles
  - one agitator with two 4 1/2" diameter impellers
- Recycle Pump
  - to pump 50% solids slurry from feed tank to head tank.
  - Flow sufficient to eliminate plugging in lines.
  - Pulp returns from head tank to feed tank by gravity overflow.

- o Head Tank
  - 20 L tank with agitator (4 1/2" dual axial-flow impeller) and baffles (2).
  - Equipped with overflow tube to feed tank, positioned so as to provide sufficient head to maintain target feed rate to RIP circuit.
  - Spigot on feed line to Tank 1 of RIP circuit; must be adjustable so that feed rate can be varied without moving overflow tube.

- o RIP Circuit
  - five 70 L vessels arranged in cascade
  - 3" diameter feed tube (downcomer)
  - 2" overflow tube positioned to provide 54 L/stage
  - each vessel equipped with 2 baffles and 1 adjustable speed agitator with two 4 1/2" dual axial-flow impellers
  - screen (48 mesh if resin is plus 32 mesh) to retain resin in each stage but allow pulp to flow. Could be either launders or screen baskets surrounding overflow tubes.
  - see Figure 18 for drawing of one RIP tank.

- o Screens
  - 65 mesh to recover resin fines from pulp discharge stream.

- o Discharge Tank
  - 45 gal drums (empty feed drums)

- o Resin Prescreening
  - 32 mesh screens.

- o Resin Advancement
  - manually, by advancing sufficient pulp with entrained resin. Must advance 4.5 L pulp every half hour. Equipment will be one plastic jug cut so as to hold 4.5 L exactly.

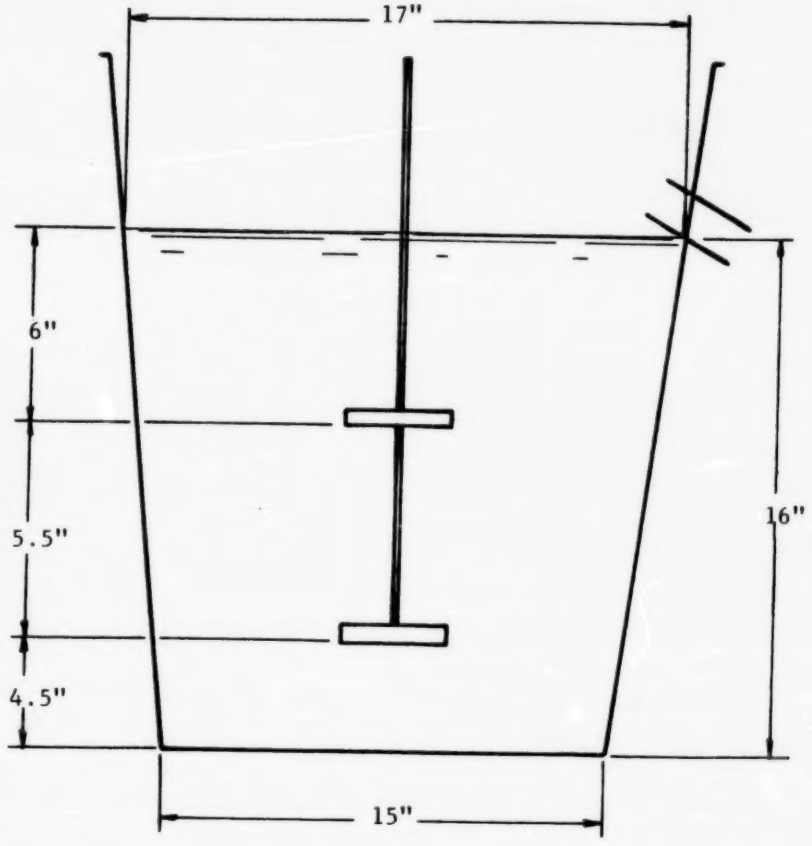

FIGURE 18: DIMENSIONS OF RIP REACTION VESSEL

o Resin Recovery- 4.5 L sample removed from tank 1 every half hour must be screened to recover loaded resin. Therefore, require four 65 mesh screens.

o Resin Elution - 12.4 g resin/h = 300 g resin/day
- batch strip in a 1 L agitated beaker.

A.5.2 Equipment List

Agitators
- 9, equipped with dual 4 1/2" axial-flow impellers (eight required at any one time plus one spare)
- 1, equipped with 18" impeller (conditioning tank)
- 1, equipped with 2" diameter teflon-coated impeller (resin elution)

Baffles - 20, two per agitated vessel, four for conditioning tank.

Meters - 1 pH meter

Titration Apparatus - for available cyanide determinations

Screens
- Sweco 65 mesh, plus vibrator
- four 32 mesh
- four 65 mesh

Screen Material - 48 mesh, to manufacture overflow launders or baskets for interstage resin/pulp screening

Pumps
- (all must be slurry pumps for 50% solids)
- one transfer pump (2.5 L/min)
- one feed pump (2.5 L/min)

Tanks	- one 1300 L Conditioning Tank
	- head tank: 20 L equipped with overflow tube to feed tank and adjustable spigot to feed RIP circuit
	- five 70 L tanks (equipped with downcomers, overflow tubes and launders)
	- Repulp Tank: Drums received (45 gal)
	- Feed Tank: One 45 gal drum
	- Discharge Tank: One 45 gal drum
Tubing	- 2" and 3" diameter for downcomers, overflow tubes plus launders
Plastic Jugs	- 10 L - require five
Beakers	- 1 L x 2
Thermometer	- 0^{o} to $100^{o}C$ - alcohol filled (not mercury)

Miscellaneous glassware, tools and sample jars

A.6.0 PRELIMINARY TESTWORK/PREPARATION FOR START-UP

A.6.1 Resin Elution: Optimization Test Program

A 100 mL sample of the prescreened resin (see Section 7.1, Resin Preparation) will be loaded batchwise using a synthetic solution of aurocyanide. The loaded resin will be divided into subsamples and eluted with various concentrations of a NaOH/NaCN solution at room temperature. The purpose of this test is to determine if higher NaOH concentrations in the eluant will allow for efficient elution of the gold at lower temperatures than those utilized during the Phase I test program, i.e. 90 to 93°C.

A.6.2 Adsorption Isotherm and Kinetics

Prior to startup, one adsorption isotherm will be produced using the authentic pulp, in order to establish maximum loading capacity of the resin and stage requirements to produce acceptable barrens. The procedure used will be similar to that utilized during Phase I, i.e., one litre of feed pulp will be contacted batch-wise with 1 mL of preconditioned resin and agitated overnight. The resin will be recovered by screening through a 65 mesh screen. For subsequent contacts, the original 1 L pulp sample will be contacted repeatedly with fresh aliquots of preconditioned resin until the pulp filtrate contains less than 0.03 mg/L Au.

Similarly, the original 1 mL resin sample will be contacted repeatedly with fresh aliquots of pulp until the gold concentration in the fresh pulp remains unchanged after contact with the resin.

In this manner, the feed pulp will be stripped completely of its gold value and the resin will be fully loaded, produced a complete loading isotherm.

In order to obain an indication of the adsorption kinetics, samples will be taken every 2 hours during the initial contact.

A.6.3 Agitation Studies

Prescreened, preconditioned resin will be mixed with pulp in the appropriate ratio (1.39 g resin/L of pulp) in a 54 L vessel equipped with baffles and dual 4 1/2" axial-flow impellers. The minimum agitation required to ensure homogeneous mixing will be determined by taking pulp samples and determining the contained resin content by screening. After each sample, the resin and pulp content will be returned to the agitated vessel prior to removal of the subsequent sample.

A.6.4 Resin Attrition Studies

The resin/pulp mixture used during the agitation study (Section 6.3) will be retained and utilized for a resin attrition study. The mixture will be agitated for 500 h at the minimal agitation rate. A representative sample of the resin will be recovered and examined under a microscope for evidence of attrition.

The above test will be repeated using a sample of carbon received from Teck-Corona. The carbon/pulp mixture will be agitated for 500 h at the minimal agitation rate.

Similarly, a sample of preconditioned resin will be agitated with 1 bed volume of eluant (see Section 6.2) for 500 h. The resin sample will be recovered and examined under a microscope for evidence of attrition.

WD1

A.6.5 Confirmation of Feed Pulp Characteristics

One week prior to startup, five drums of feed pulp will be chosen at random. The slurry will be repulped until homogeneous, and the time required for repulping noted. The slurry pH will be recorded and two 500 mL samples will be removed from each drum. One sample will be used to determine pulp density, and percent solids. The second sample will be filtered. The filtrate will be assayed for Au, Zn and available cyanide. The solids will be dried, pulverized and assayed for gold. The assay results will indicate if a brief cyanidation leach is required to resolubilize the gold. Operating parameters will be adjusted according to the actual chemical composition of the feed solution (i.e., resin to pulp feed ratio, resin inventory per stage, etc.).

A.7.0 MATERIAL PREPARATION

A.7.1 Resin Preparation (week prior to start-up)

A.7.1.1 Resin Prescreening

A preliminary screening test on the as-received resin (20 to 50 mesh) indicated that the resin is approximately 85% plus 32 mesh. Removal of the minus 32 mesh fraction will facilitate resin/pulp separation and decrease resin/gold loss in the RIP circuit. Therefore the resin will be soaked over in pH 10 lime water and prescreened to 100% plus 32 mesh.

A.7.1.2 Resin Preconditioning

In order to avoid the use of "new" resin during the pilot campaign, the prescreened resin will be batch-loaded using a synthetic solution of zinc cyanide (no gold present so as not to complicate overall gold balance for pilot campaign). The loaded resin will be eluted using the optimal eluant (see Section 6.1) until a resin assay indicates less than 1 mg Zn/L of resin remaining. The preconditioned resin will be stored under pH 9 to 10 lime water prior to use.

A.7.2 Pulp Preparation (during pilot plant campaign)

Each drum must be opened, repulped and transferred to the conditioning tank. After each addition of pulp to the conditioning tank, the pulp will be agitated until homogenous and measured for pH and available cyanide. The pH will be adjusted to about pH 10 (9.8 to 10.2) using lime. If the available cyanide level is greater than 0.2 g/L CN, then no additional cyanidation step is required. If not, the available cyanide level must be increased and maintained above 0.2 g/L CN for about 30 minutes by the addition of NaCN to ensure complete solubilization of the gold.

WD1

Immediately prior to transfer to the feed drum, the slurry pH will be checked and adjusted to 9.8 to 10.2 using lime, if required. During transfer to feed tank, slurry will be screened to 100% minus 65 mesh using a Sweco vibrating screen.

Each drum contains about 150 L or sufficient feed for about 5 1/2 hours of operation. Therefore, repulp and transfer five drums at once, once per day.

A.8.0 STARTUP PROCEDURES FOR RIP CIRCUIT

A.8.1 First Campaign

- Ensure at least five drums of feed pulp are repulped
- Transfer at least five drums of pulp through 65 mesh Sweco screen into conditioning tank. Start conditioning tank agitator.
- Check pH of pulp in conditioning tank. Adjust to pH 9.8 to 10.2 using lime. If pH is greater than 10.2, do not adjust.
- Check available cyanide levels. Adjust to about 0.2 g/L available CN by addition of NaCN.
- Open spigot between conditioning tank and feed tank. Allow feed tank to fill to about 3/4 full. Start feed tank agitator.
- Start recycle pump to head tank at desired rate.
- Start head tank agitator
- Once head tank is full to overflow, open spigot of head tank to achieve desired feed rate to RIP circuit (0.27 L/h or 450 mL/min).
- Allow pulp to overflow consecutively to each of 5 stages.
- As each RIP tank is filling with pulp add 70 mL of resin.

- Turn on agitator in each RIP tank as required.

- After about 10 h of operation, pulp will begin to overflow final stage into discharge drum. At this stage begin first resin advance (see instructions Section 9.1).

- Throughout start-up, check pulp feed rate to stage 1 frequently, i.e. every 1/2 hour until convinced that feed rate is steady and then every 2 hours thereafter.

A.8.2 Second Campaign

- Turn on all agitators and repulp slurry in all tanks.

- Measure pH in each tank and adjust to pH 9.8 to 10.2 using lime.

- Measure available cyanide. If below 0.2 g/L CN increase using NaCN, agitate for 30 minutes to ensure complete gold solubilization.

- If conditioning feed tank is empty, ensure that five drums of feed pulp are prepared and transfer to conditioning tank after screening through 65 mesh screen. Start conditioning tank agitator.

- Fill up feed tank to 3/4 full. Start feed tank agitatior.

- Start recycle pump at desired rate.

- Once head tank starts to overflow, open feed spigot and adjust to desired feed rate.

- Begin first resin advance after 10 hours of operation.

A.9.0 OPERATING PROCEDURES

A.9.1 RIP Circuit

A.9.1.1 Feed Pulp Preparation

- Measure volume of pulp contained in each new drum of feed pulp as height in cm. Record in log book.

- During each addition of pulp to conditioning tank, close spigot to feed tank. Measure the pH and available CN level of the pulp in the conditioning tank after each addition. Record in log book. Adjust to pH 9.8 to 10.2 using lime. If above pH 10.2 do not adjust. Adjust to about 0.2 g/L available CN (0.4 g/L NaCN) using NaCN. Record addition quantities of lime and NaCN in log book.

- If cyanidation leach is required, maintain pH and cyanide levels for one hour to ensure complete gold solubilization. Record reagent additions in log book.

A.9.1.2 RIP Operators

- Check feed rate of pulp from head tank to RIP tank 1 every hour. Record in Log Book.

- Check pH of slurry in the feed slurry and tank 5 discharge slurry every 2 hours and record in Log Book.

- Check pulp density of feed slurry and tank 5 discharge slurry every 2 hours and record in Log Book.

WD1

- Advance resin every 1/2 hour as follows:
  - -remove 4.5 L of pulp from Tank 1. Screen through 65 mesh screen to recover resin quantitatively. Pulp returns to Tank 1. Store resin in pH 9.5 lime water; composite over 24 h. Resin composites proceed to elution.
  - -transfer 4.5 L of pulp from Tank 2 to Tank 1, Tank 3 to Tank 2 and Tank 4 to Tank 3, in that order.
  - -add 6.2 g of fresh resin to Tank 4.

- Take samples as outlined in Sample Schedule below.

A.9.2 Elution Circuit

- Take 24 hour composite resin sample and wash once with pH 9.0 to 9.5 lime water. Remove one 3 mL sample and one 20 mL sample. Add 3 mL sample to campaign composite. Submit 20 mL sample for Au and Zn analysis.

- Contact remaining resin batchwise with 1 bed volume of eluant (1% NaCN, 1% NaOH in distilled water) in a 1 L beaker.

- If increased temperatures are required then seal beaker and provide one air vent and one hole for thermometer.

- Agitate for 30 minutes retention time. Decant and wash resin with 1 BV of pH 9.0 to 9.5 lime water (same temperature as eluant).

- Combine eluate and wash, and assay for Au

- Repeat 15 times or until gold removed is negligible.

- Retain one 3 mL and one 20 mL sample of eluted resin . Add 3 mL sample to campaign composite and assay 20 mL sample for Au and Zn.

- Form composite of all eluate samples and assay for Ag and Zn.

- Store eluted resin under pH 9.0 to 9.5 lime water until returned to RIP circuit.

A.10.0 SHUTDOWN PROCEDURES FOR RIP CIRCUIT

A.10.1 First Campaign

- Take final round of samples (Section 12).
- Turn off feed pump and close feed spigot from head tank to Tank 1. Leave agitators on.
- Check pH of each tank (feed, head and five RIP tanks) and increase to pH 10.5 using lime.
- Check available CN level in each tank and adjust to 0.3 g/L CN using NaCN.
- Turn off agitators.
- Cover all tanks as well as possible.
- Work up all remaining samples and submit for analysis
- During shutdown period check and maintain slurry pH and available cyanide levels periodically.

A.10.2 Second Campaign

- Take final round of samples (see Section 12, sample schedule).
- Turn off feed pump and close feed spigot from head tank to Tank 1. Leave agitators on.
- Use transfer pumps to remove pulp from each tank of RIP circuit.
- Screen contents of each tank through an 65 mesh screen.
- Store pulp from each tank separately in labelled, sealed pails.
- Recover resin quantitatively. Wash resin with pH 9.0 to 9.5 lime water. Store resin from each stage separately under lime water in labelled containers.

- o Note volume of pulp (measure height in cm) remaining in head tank and feed tank. Record in log book.
- o Return contents of head tank and feed tank to drums and seal.
- o Seal all discharge tanks.
- o Work-up all remaining samples and submit for analysis.

A.11.0 MANPOWER REQUIREMENTS AND RECOMMENDED SHIFT SCHEDULE

The proposed programme (Witteck Proposal 171) called for a 16 hour startup/shakedown period followed by two 10-day compaigns, no scheduled shutdown, 12 hour shifts.

Due to the length of the campaign, it is recommended that no more than four 12 hour shifts or ten 8 hour shifts be worked in series. Therefore, 8 hour shifts are recommended, with one scheduled shutdown period between two 10-day campaigns.

In addition, 1 person, 8 hours/day is required for elution plus sample workup and 1 person, 8 hour/day is required for supervision. The project manager will be available as required.

The proposed shift schedule is as follows:

- RIP Circuit: Operator 1 00:00 to 08:00 h
  Operator 2 08:00 to 16:00 h
  Operator 3 16:00 to 24:00 h

- Elution Circuit: 1 person 00:00 to 08:00 h

- Supervision: 16:00 to 24:00 h

- Project Management: 08:00 to 16:00 h
  (as required)

The project manager will be available as required for discussion or assistance.

During the off-shifts (i.e. 00:00 to 08:00 and 16:00 to 24:00) there will always be two people working at all times to meet safety regulations.

The detailed schedule for the 20 day campaign is provided in Table 1 and breaks down as follows:

o	Startup/Shakedown	2/3 day
o	1st Campaign	9 2/3 days/24 h per day
o	Shutdown	1/3 day
o	Break	3 days
o	2nd Campaign	9 2/3 days/ 24 h per day
o	Shutdown	1/3 day
o	Break	4 days
o	Cleanup	2 people/2 days
o	Sample Followup; Data Collection	1 person/2 days

Total manpower requirements: 5 people during pilot plant operation.

A.12.0 SAMPLE SCHEDULE

A.12.1 Feed Pulp

- o Daily Composite: (take one 25 mL sample every 2 h, composite over 24 h)
  -Assay solution for Au (by AA) and Zn

- o Campaign Composite: (take one 25 mL sample every 2 h, composite over 10 days).
  -Assay solution for Au, Ag, Cu, Fe, Ni, Zn, As, Sb, Hg, Mo
  -Assay solids for Au

A.12.2 Profile Samples : Feed and Discharge from RIP Tanks 1 to 5

sample once every hour, composite over 8 hours
-Feed, Tank 1, Tank 2: take 25 mL samples
-Tank 3, Tank 4: Tank 5 take 150 mL samples
-Assay solution for Au (Feed plus tanks 1 and 2 by AA, tanks 3 4 and 5 by Chiddey)

A.12.3 Discharge Pulp

- o Daily Composite (take one 100 mL sample every 2 h, composite over 24 h)
  -Assay solution for Au (Chiddey) and Zn

- o Campaign Composite (take one 25 mL sample every 2 h, composite over 10 days)
  -Assay solution for Au, Ag, Cu, Fe, Ni, Zn, As, Sb, Hg, Mo
  -Assay solids for Au

A.12.4 Resin Samples

- o Daily Composite - (composite over 24 h)
  -Assay loaded resin for Au and Zn
  -Assay stripped resin for Au and Zn

o Campaign Composite - (composite over 10 days)

-Assay loaded and stripped resin for other elements which appear to load on to the resin, based on analysis of comapign composites of feed and discharge solutions.

o Microscopic Examination

-A sample of each of the four campaign composites will be examined by scanning electron microscopy. Comparison of fresh resin, to resin after 10 days and 20 days of operation will indicate amount of attrition.

A.12.5 Eluate (Strip resin once per day)

-5 samples per day for Au
-1 sample per day for Zn.

A.12.6 Daily Requirements

o Solution Samples:	25 Au
	3 Zn
o Solid Samples:	2 Au
o Resin Samples:	2 Au
	2 Zn

A.13.0 SAMPLE PREPARATION

A.13.1 RIP Circuit

A.13.1.1 Feed Pulp (Take two 25 mL samples every 2 hours)

(a) Take one 25 mL sample of feed pulp every 2 hours. Adjust pulp to pH 12 by adding NaOH pellets. Composite over 24 hours (check pH after every addition and add more NaOH as required). After last sample addition, filter sample.

Solution: Stabilize to pH 12 using NaOH. Submit for Au and Zn assay.

(b) Take one 25 mL sample of feed pulp every 2 hours. Adjust pulp to pH 12 by adding NaOH pellets. Composite over 10 day campaign (check pH after every addition and add more NaOH as required). After last sample addition, filter sample.

Solution: Stabilize to pH 12 using NaOH. Assay for Au, Ag, Cu, Fe, Ni, Zn, As, Sb, Hg, Mo.

Solids: Dry, pulverize and submit for Au assay.

A.13.1.2 Profile Samples (Take samples every hour)

(a) Feed Line, Tank 1, Tank 2 - Take one 25 mL sample every hour. Take sample from launder discharge to avoid screening samples to recover the resin. Adjust pulp samples to pH 12 using NaOH pellets. Composite over 8 h. shift. Filter sample.

Solution: Stabilize to pH 12 using NaOH. Submit for Au (by A.A.).

(b) Tank 3, Tank 4, Tank 5 - Take one 150 mL sample every hour from launder discharge. Adjust pulp to pH 12 by adding NaOH pellets. Composite over 8 h. shift. Filter.

Solution: Stabilize to pH 12 using NaOH. Submit for Au (by Chiddey).

A.13.1.3 Discharge Pulp (Take two samples every 2 hours)

(a) Take one 100 mL sample of discharge pulp every 2 hours from launder discharge. Stabilize pulp to pH 12 using NaOH pellets. Composite over 24 hours (check pH after every addition and add NaOH as required). After last addition, filter sample.

Solution: Stabilize to pH 12 using NaOH. Submit for Au and Zn assay.

(b) Take one 25 mL sample of discharge pulp every 2 hours from launder discharge. Stabilize pulp to pH 12 using NaOH pellets. Composite over 10 day campaign. (Check pH after every addition and add NaOH as required). After last addition, filter.

Solution: Stabilize to pH 12 using NaOH. Assay for Au, Ag, Cu, Fe, Ni, Zn, As, Sb, Hg, Mo.

Solids: Dry, pulverize solids and submit for Au assay.

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A.13.2 Elution Circuit

A.13.2.1 Resin Samples

Receive daily resin-advance sample from RIP operator. It will be stored under lime water, pH 9 to 9.5, and should contain about 300 g of resin. Measure wet settled volume, tap well to insure minimal volume. Remove one 2 mL sample and one 20 mL sample. Add 2 mL sample to campaign composite. Submit 20 mL sample for Au and Zn assay. Record volume of remaining resin. Resin proceeds to elution.

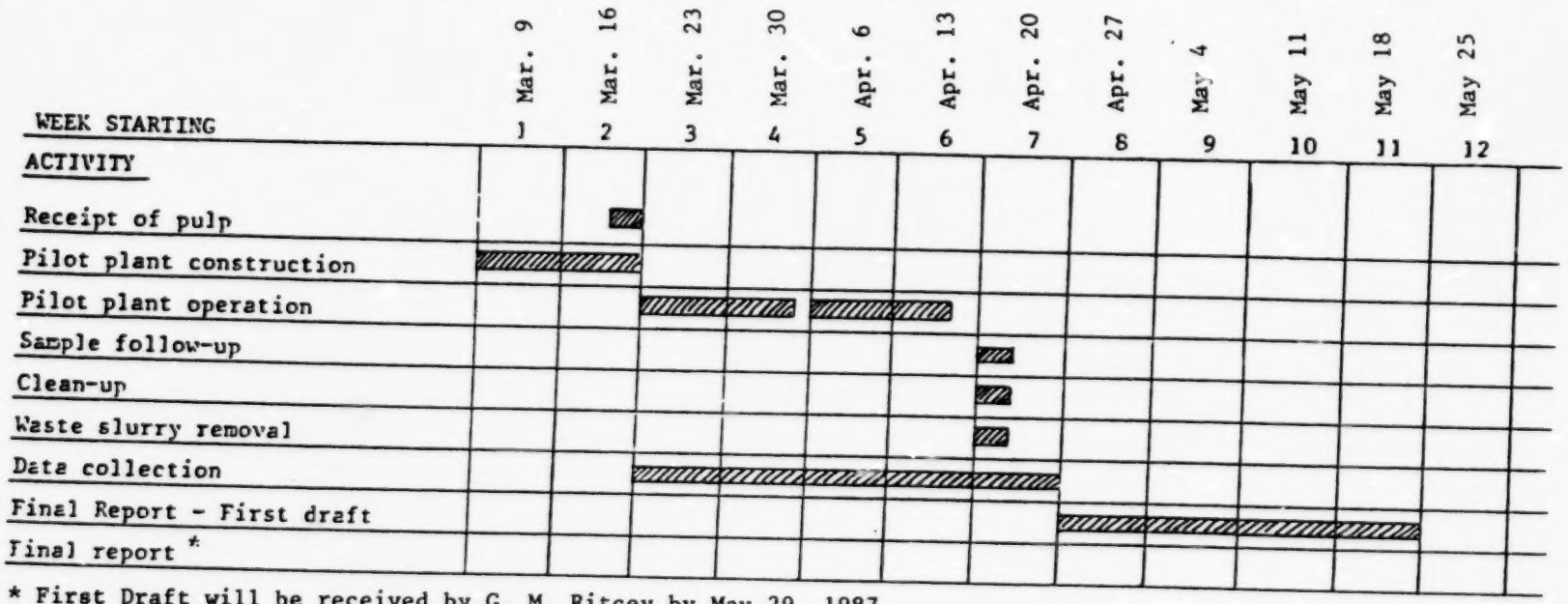
At end of each 10 day campaign, submit campaign composite for Ag, Cu, Fe, Ni and any other elements of interest.

A.13.2.2 Eluate Samples

During first few days, assay every bed volume for Au until typical elution curve is established. During subsequent days, spot check every few bed volumes to determine when Au is no longer eluting. Combine all eluate bed volumes and wash solution in a volumetric, dilute to mark and assay for Ag and Zn.

TIME LINE

Table 2



* First Draft will be received by G. M. Ritcey by May 29, 1987.
Final Report will be received by DSS no later than June 26, 1987.

A.15.0 LOG BOOK

All data will be recorded in the operator's Log Book, including operating parameters/measurements and assay results. In addition, space will be provided for comments concerning operation, e.g. shutdown time and reasons, spillage, operational problems and solutions, etc.

APPENDIX B

Pilot Plant Operating Parameters

APPENDIX B

PILOT PLANT OPERATING PARAMETERS

The pilot plant operating parameters were selected on the basis of the data obtained during the Phase I test program, calculated requirements and the constraints imposed by the contractual agreement in terms of work scope, time and budget.

The original proposal for Phases I through III set the general pulp flowrate for Phase II by specifying that 0.5 tons per day would be treated through the RIP pilot circuit.

The corresponding resin flowrate was based on the resin loading capacity achieved during the benchscale and mini-pilot plant operations of Phase I.

Resin inventory in each stage of the RIP circuit was considered to be critical and was set at a level that would permit the pilot plant operation to proceed, i.e. attain the stated objectives within the constraints listed above. The minimum inventory that could be used under continuous operating conditions was calculated to be three times the advancing volume of resin per pulp retention time on the basis of the general equation:

$$Q = e^{-t}$$

Where: Q = quantity of original material remaining at time "t" as displaced by new material (material in this application is the resin).

t = time

It can be shown that each advancing volume of pulp is in contact with twice the advancing volume of resin in each stage. This contact is marginal if compared with the contact provided in other generally similar processes as shown below:

	Concentration in Pulp, mL/L	Contact per Pulp Volume per Stage *
Resin-in-Pulp (Pilot Plant)	1.39	2
Carbon-in-Pulp (Gold)	15 to 40	20 to 59
Resin-in-Pulp (Uranium)	30 to 45	44 to 46
Resin-in-Solution (Uranium, Upflow)	300	450

* All calculations on the same basis as the pilot plant

Alternatively, the selected inventory of resin (3 volumes) provided for one resin inventory to be in contact with the last remaining pulp per stage flush (i.e. 3 pulp displacements flush out 95% of the pulp, leaving 5% of the residual volume of pulp in contact with one advance volume of resin). This ensures that nearly all of the pulp sees at least one advance volume of resin.

The following operating parameters allow for completion of the program within the time frame (two 10-day runs) outlined in the proposal.

Pulp:

Pulp in tank	54 L
Pulp flow	27 L/hour
Pulp retention time per tank	2 hours
Time to flush tank (95% removal)	3 displacements or 6 hours
Time to flush the pilot plant (or 1 pulp cycle)	6 hours x 5 tanks = 30 hours

WD1

Resin:

Resin in tank	72 mL
Resin flow	12 mL/hour
Resin retention time per tank	6 hours
Time to flush resin in tank (95% removal)	3 displacements or 18 hours
Time to flush the pilot plant (or 1 resin cycle)	18 hours x 5 tanks = 90 hours

The pilot plant schedule was designed as follows:

	Hours	Days
Reach steady state Collect loaded resin	90	4
Operate at steady state Elute loaded resin	48	2
Recycle Eluted resin Reach steady state Collect loaded resin	90	4
Total Time, Run 1	228	10

Some parameters would then be changed and the pilot plant would be operated for the remaining 10 days as permitted by the budget and as outlined in the proposal. In this manner, one full cycle could be completed using eluted resin within the 10-day time constraint, and the stated objectives of the pilot plant could be achieved.

However, if a resin concentration of 15 mL/L were used (rather than 1.39 mL/L), to more closely simulate plant practice for carbon-in-pulp circuits, the pilot plant schedule would be as follows:

	Hours	Days
Reach steady state, Collect Loaded Resin	1012	42

Under such conditions, the time and budget allowance for the project would be exceeded before steady state was reached and the objectives of the program would not be realized.

Therefore, the resin inventory in each stage was designed so as to allow for the most amount of information to be obtained, and the program objectives to be met within the guidelines of the proposed work scope. However, it was understood that the corresponding opeating parameters might not be representative of future full-scale commercial resin-in-pulp operations.

WD1

APPENDIX C

Critique of the Design and Operation of RIP Pilot Plant

APPENDIX C

CRITIQUE OF THE DESIGN AND OPERATION OF RIP PILOT PLANT

C.1.0 RUN 1 OF PILOT PLANT PROGRAM

Figure 19 presents graphical information on the design and operation of the first pilot plant run. All equilibrium and distribution curves have been assumed to be straight lines. In reality, the curves are probably not straight lines, but the assumption is generally considered valid for evaluations of this nature and permits cleaner presentation and analysis of the data. A description of the curves follows:

Curve A:

Curve A is the 24 hour Contact Isotherm (24 Hour Equilibrium Curve) determined for the resin during the Phase I test program. (The Phase II pilot plant was designed based on the information obtained during the Phase I study). The following equilibrium information is obtained from Curve A.

Resin, Au g/L 24 hours	Solution, Au mg/L 24 hours
10.0	0.68
1.0	0.068
0.1	0.0068

Curve B:

Curve B is the design Operating Distribution Curve which was used to design Run 1 of the pilot plant program. The calculation of the curve was based on Phase I kinetic information for the resin, which indicated that 68% of the 24 hour equilibrium resin loading was obtained during the first two hours of contact.

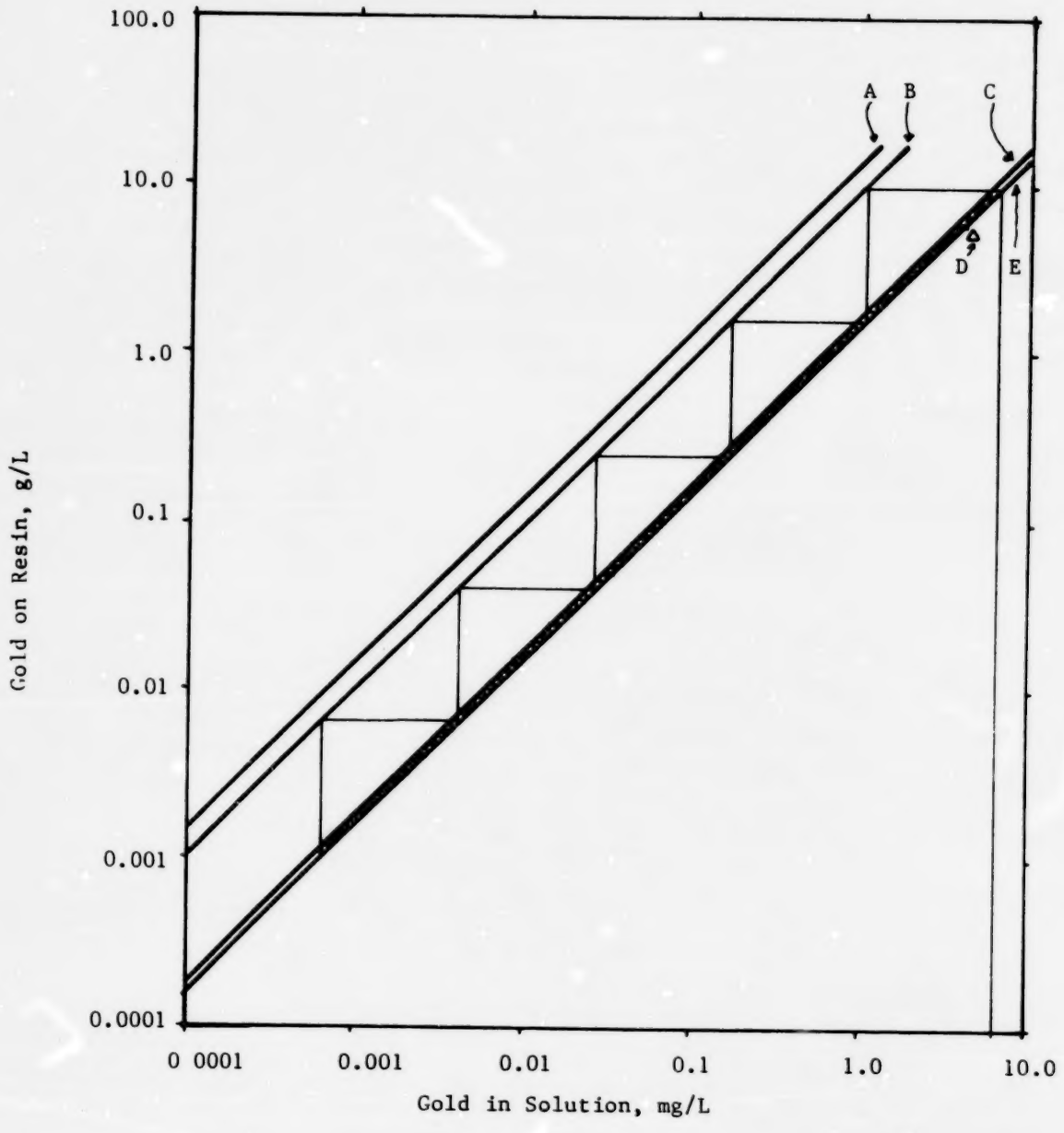


FIGURE 19: DESIGN AND OPERATION OF RUN 1

The basic assumption was that the resin would load to 68% of equilibrium loading in 2 hours and that the resin was in contact with solution representative of 24 hour eqilibrium (i.e. 1 mL of resin in contact with a very large volume of solution). The resin/solution volume ratio used during the initial pilot plant run (1.39 mL resin per litre of solution) was similar to that used during Phase I (1 mL resin per litre of solution). Curve B was calculated as follows:

Resin, Au g/L 24 hour		Resin, Au g/L 2 hour	Solution, Au mg/L 24 hour
10.0	x 68%	6.8	0.68
1.0	x 68%	0.68	0.068
0.1	x 68%	0.068	0.0068

Although the assumption with respect to true equilibrium is valid, the assumption does not appear to be valid in terms of relating the kinetic testwork of Phase I to the development of an operating distibution curve suitable for predictions of pilot plant operations. Under the assumed conditions, a very long time would be required to achieve 68% of the equilibrium loading and this amount of time would not be available in the pilot plant and is considered unrealistic.

The 24 hour equilibrium curve was developed by contacting 1 mL of resin with 1 L of solution. Both quantities (resin and solution) are finite and the ever increasing degree of 24 hour equilibrium attained with increasing contact time would be reflected in the changes in gold concentration of both the resin and the solution.

Accordingly, a mass balance should be used to estimate the 2 hour contact distribution curve. A balance on the basis of 68% of equilibrium loading is required for each point examined on the 24 hour equilibrium curve to calculate the corresponding point for the 2 hour contact operating distribution curve.

Curve C:

The true Operating Distribution Curve (Curve C) was calculated as follows:

1 mL Resin + 1 L Solution, 24 hour Contact, Equilibrium

Resin Au g/L	Solution Au mg/L	Total Au mg
10.0	0.68	10.68
1.0	0.068	1.068
0.1	0.0068	0.1068

1 mL + 1 L Solution, 2 hour Contact, 68% Equilibrium

Resin Au g/L	Solution Au mg/L	Total Au mg
6.8	3.88	10.68
0.68	0.388	1.068
0.068	0.0388	0.1068

It should be stated that the above procedure is an approximation of the operating distribution curve. The degree of equilibrium attained is dependent on resin characteristics, the resin concentration in the contactors, and the degree of agitation in addition to contact time. It is known that the resin used in the pilot plant was a different batch than that used for Phase I, and it has been reported that the degree of agitation used during the Phase I program could be considered extremely violent relative to the degree of agitation used during pilot plant operations. (During the pilot plant operation, agitation was designed to more closely simulate the agitation used in commercial CIP operations).

For a better determination of an operating distribution curve for the pilot plant, testwork to determine kinetics and gold distribution should be performed in the actual pilot contactors under conditions representative of pilot operations.

Curve E:

Curve E is the design operating line for the initial pulp (solution) and resin flowrates. Resin flowrates were based on a predicted loading of 10 g Au/L resin. The flows were 27 L/h pulp (18.9 L/h solution) and 12 mL/h resin. The slope of the operating line was calculated to be 1575. A McCabe-Thiele graphical determination of the number of theoretical stages required to achieve a desired barren can be performed utilizing the design operating line (curve E) and the operating distribution curves (curves B and C).

Point D:

Point D shows the concentrations of the resin and solution in Tank 1 of the pilot plant just before completion of Run 1. Complete information on resin and solution concentration for the other tanks is not available. Although Point D is located below the operating line (Curve E), it is sufficiently close to the line to suggest that the actual location may be due to small operating variations within the pilot plant. Complete steady state operation may not have been achieved, or the variations may be just natural oscillations for the system. Point D is also possible because of resin saturation.

The McCabe-Thiele determination indicates that 3 or 4 theoretical stages would be required to obtain an acceptable barren (0.01 mg/L Au in solution) utilizing the design operating distribution curve, Curve B and assuming a feed concentration of 6.5 mg/L gold in solution. On this basis, selection of 5 stages for the pilot plant appeared to be reasonable.

However, utilizing the more realistic distribution curve, Curve C, the number of stages required to achieve the same barren would be in the order of 50 to 60. This is completely unrealistic in terms of the pilot plant or in terms of a full-scale operation.

The projected barren with the 5 stages provided in the pilot plant using Curve C is 3.0 to 3.5 mg/L. The closeness of the operating distribution line (Curve C) to the design operating line (Curve E) makes graphical determination of the number of stages and the barren concentration difficult.

There are other factors that also must be considered. These include the equilibrium and kinetic characteristics of the actual resin used during Run 1 of the pilot plant campaign, as opposed to that used during the Phase I program.

Figure 13 (Section 7.1.2) presents the 24 hour equilibrium curve for the plus 32 mesh fraction of resin B & C used during Run 1 of the pilot program.

The maximum equilibrium loading (24 hour) for the resin is 7.3 mg/L when in contact with 6.0 mg/L Au in solution. The 2 hour loading would be lower.

Figure 14 (Section 7.1.2) presents the adsorption rate for the plus 32 mesh fraction of resin B & C. In two hours contact, 68% of the equilibrium (24 hour) condition was obtained, and in ten hours contact 92% of the equilibrium condition was obtained.

Combining of the information from Figures 13 and 14 indicates that a resin loading of 5.0 g/L at 2 hours contact and 6.7 g/L in 10 hours contact. These loadings are significantly lower than the design loading of 10 g/L and, therefore, the pilot plant would be operating with insufficient resin to permit adsorption of all the gold.

Under these circumstances, the five-stage plant could be considered to be operating similar to a one-contact system with saturated resin (saturated in terms of what the resin could adsorb in the contact time allowed). The actual contact time for such a system would be somewhere between 2 and 10 hours. The resin loadings and barren produced under these conditions might be as follows:

Contact Time hours	Resin Loading Au g/L	Barren Au mg/L
2	5.00	3.33
10	6.70	2.25
(median)	5.85	2.79

Point D can now be explained as being a resin saturation point, rather than an equilibrium point.

C.2.0 RUN 2 OF PILOT PLANT PROGRAM

Figure 20 presents graphical information on the design and operation of the second pilot plant run.

Curves A, B and C are the same as described for Figure 19, for Run 1 of the pilot plant run program.

Curve E, the new operating line for the final conditions used during Run 2, was calculated on the basis of the relative flows of 9.3 L/h pulp (6.5 L/h solution) and 20 mL/h resin for a calculated slope of 325.

Curve D is the distribution line developed from the actual resin and solution data from the five contactors with an extrapolation to the lower barren concentration levels.

Projections on the basis of Curve C show that an acceptable barren could be achieved with five theoretical stages.

Projections using the extrapolated distribution curve, Curve D, indicated that results are similar to those obtained with the calculated curve. However, the actual barren achieved with five actual stages was much higher. A summary of the projected and actual results is shown below.

	Barren, Au mg/L
5 Pilot Plant Stages	0.10
5 Theoretical Stages (Calculated Curve C)	0.001
5 Theoretical Stages (Extrapolated Curve D)	0.001

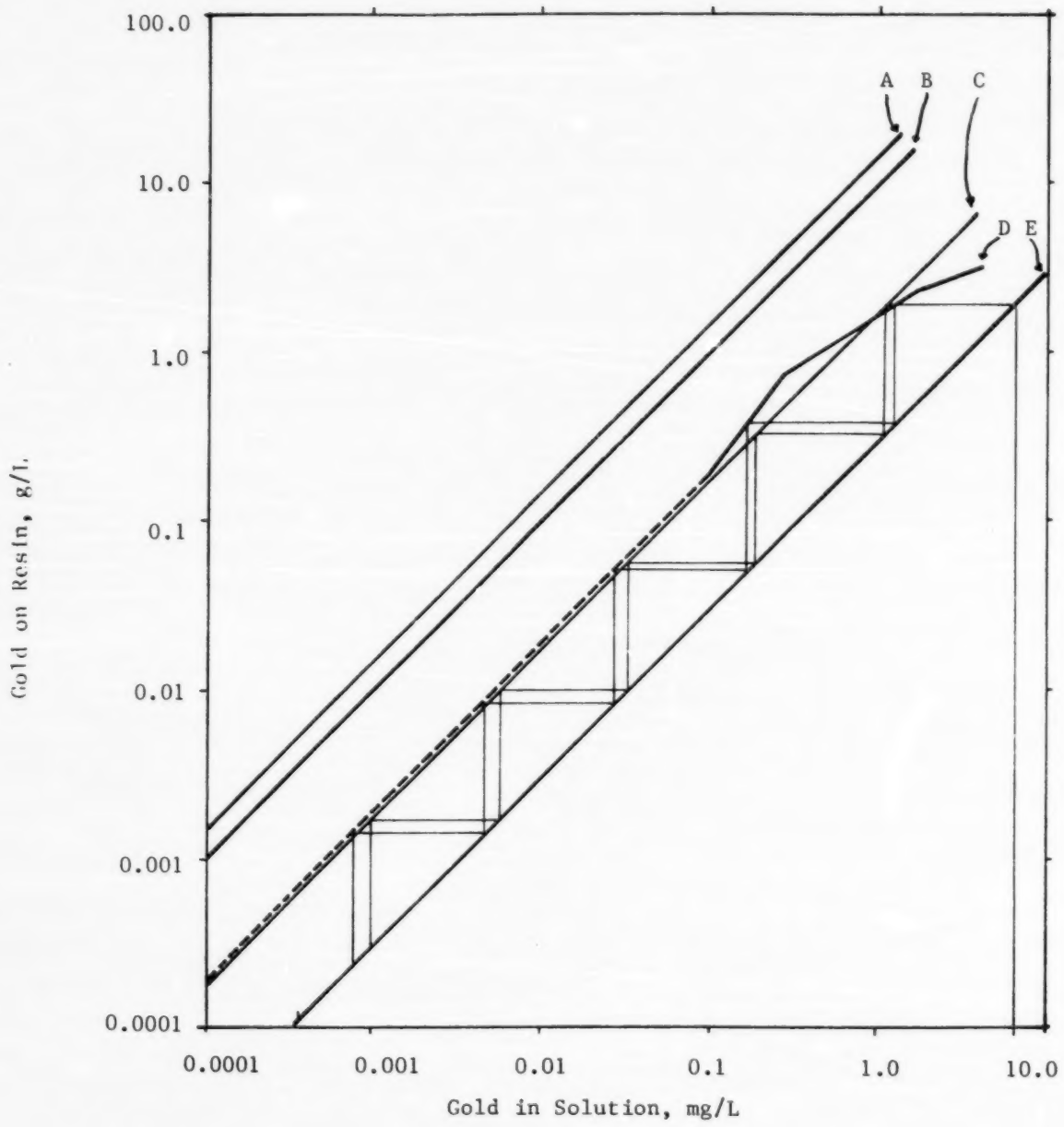


FIGURE 20: DESIGN AND OPERATION OF RUN 2

The discrepancy between actual and projected performance could be dependent on several factors:

- The resin remaining in each contactor after Run 1 was used for Run 2. Since a resin saturation condition might have existed during Run 1, steady state conditions may not have been achieved before the end of Run 2.

- Eluted resin was recycled through the system during Run 2. Residual gold on the eluted resin may have prevented low barrens from being achieved because of an unfavourable equilibrium condition.

- The difference between the actual and projected performance could very well be a result of the inefficiency of the actual contactors. The theoretical stages are 100% efficient, but the efficiency of an actual contactor could be significantly lower.

- Also, it should be noted that the retention time per stage was increased to 6 hours from the original 2 hours because of the reduced pulp flow. This would increase the percentage of 24 hour equilibrium achieved and would result in Curve C moving closer to the 24 hour curve. The new position of Curve C was not recalculated because the net effect on the overall results would not be significant.

C.3.0 DESIGN FOR 5 G/L RESIN LOADING

Figure 21 presents graphical information on the design of the pilot plant operations on the basis of a resin loading of 5 g/L. On the basis of the equilibrium and kinetic data available for the resin fraction in use (Resin B & C), the 5 g/L loading appears to be the maximum possible under pilot conditions.

Curves A, B and C are the same as described for Figure 19.

Curve E is the operating line for the new phase flows of 27 L/h pulp and 24 mL/h resin and has slope of 788.

Curve D is an extrapolated curve on the basis of the resin and solution concentrations in Tank 1 at shutdown of the final run.

On the basis of Curve C, 8 to 9 theoretical stages would be required to achieve a reasonable barren of 0.01 mg/L Au. On the basis of Curve D, 13 to 14 stages are indicated for the same barren level.

These requirements appear may be excessive when compared to other available gold adsorption processes. An engineering feasibility study is recommended, comparing estimated capital and operating costs for resin-in-pulp and carbon-in-pulp, using the 5 g/L loading capacity for the resin.

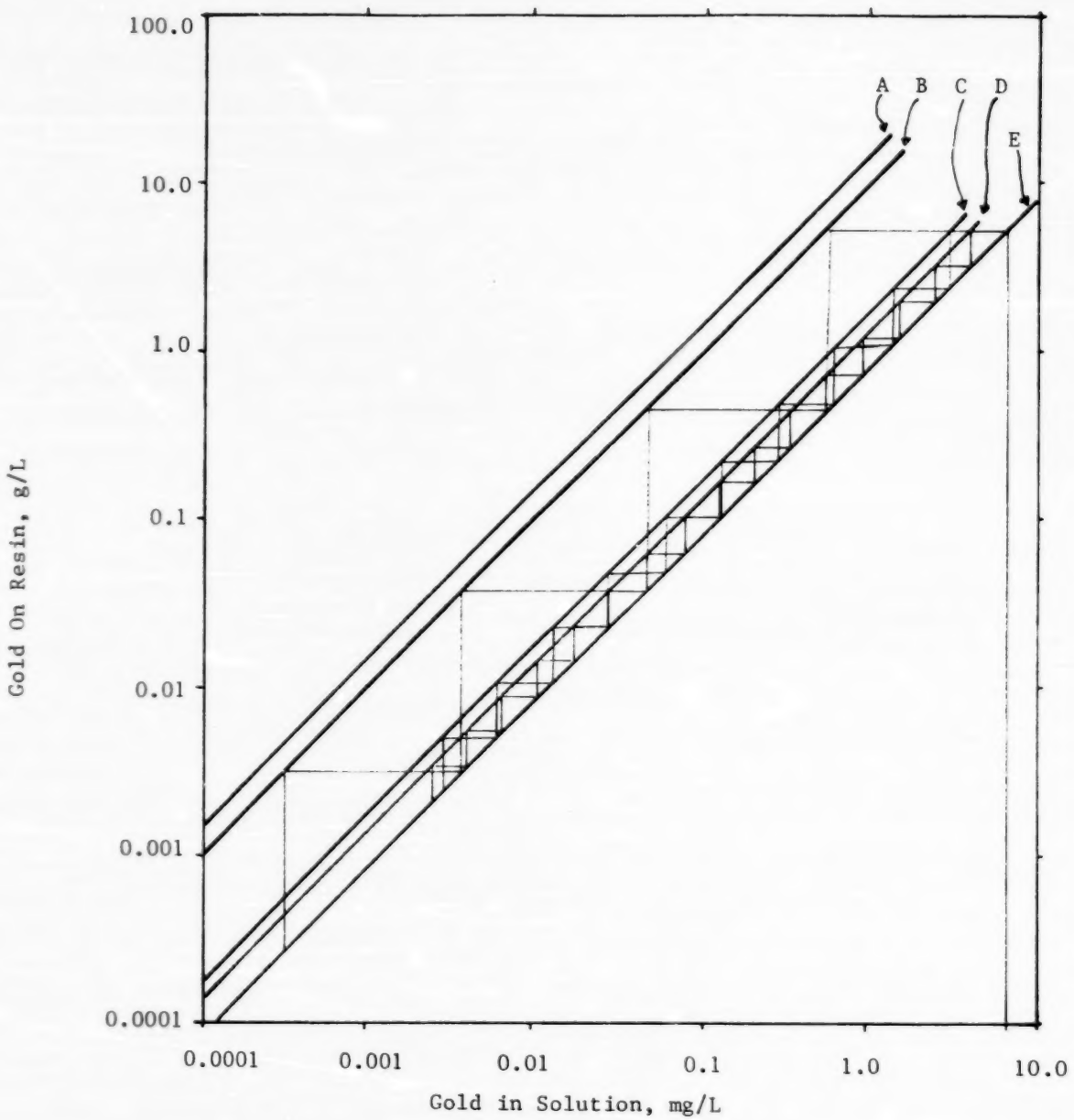


FIGURE 21: DESIGN FOR 5 g Au/L RESIN LOADING

APPENDIX D

ANALYTICAL PROCEDURES

Solution Assays

All quantitative solution assays were performed in-house. Metals (Co, Cu, Fe, Ni Ag, Zn) were assayed directly either by Atomic Adsorption (AA) or by Direct Current Plasma (DCP). Arsenic and antimony were determined by the vapour generation technique and completed by AA. Gold was assayed directly as described above at levels greater than 0.05 mg/L. Low level gold solutions were preconcentrated by the CHIDDEY method, fire-assayed and completed by AA.

Semi-quantitative multi-element analyses were carried out by Assayers Ltd. of Toronto, Ontario.

Resin Analysis

Resin samples were acid digested and the resulting solutions were assayed directly for base metals by AA or DCP. Resins were assayed for gold and silver by fire assay, followed by acid digestion and finished using AA or DCP.

Solids

Solids were assayed for gold by the fire assay method, followed by acid digestion and finished using AA or DCP.